Final Report
Heavy Bomber Industrial Capabilities Study

Prepared Under Contract to:

Under Secretary of Defense
(Acquisition and Technology)

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SUMMARY

This report, prepared in annotated briefing format, presents the analysis performed by TASC Inc. as part of the Congressionally-mandated ***FY95 Heavy Bomber Study***, and provides findings and recommendations resulting from this analysis. A summary report on the same subject, entitled ***Executive Summary: Heavy Bomber Capabilities Study***, was delivered to Congress in July 1995.

This study examines a critical issue facing the Department of Defense (DoD) as procurement levels and new program starts decline. Will reduced procurement result in the loss of industrial capabilities required to design, develop, produce, and maintain advanced military systems? And, will today's acquisition decisions do irreparable harm to our ability to obtain new systems when they are needed in the future?

This issue is central to TASC's assessment of industrial capabilities that support the B-2 bomber. Although some believe that the most expedient way of maintaining essential bomber capabilities is to continue to purchase additional B-2s, the issue is clouded by concerns about the need for more of these systems, their uncertain utility in meeting present-day threats, and concern that the B-2's cost would inevitably crowd out other, high-priority investments.

The importance of our current industrial capabilities in supporting a B-2 production restart or building a future heavy bomber cannot be ignored. The purpose of this study is, therefore, to determine the viability of capabilities essential to heavy bombers, and to assess the impact of closing down the B-2 program on industry's ability to support a B-2 restart or a future bomber program.

Core Industrial Capabilities

Unlike a few highly specialized defense-unique items, the B-2 is fundamentally an aircraft like many others -- albeit an extremely complex aircraft that poses many design and manufacturing challenges. There is no discrete "bomber industry", and from the prime level through the subtiers, bomber companies also supply other aircraft programs with essentially the same items that are supplied to the B-2. The B-2's design is certainly different from that of other aircraft, and is generally more complex, but the industrial capabilities that are applied to meet the different design and manufacturing requirements are essentially the same. Thus, the viability of the "bomber industry" will be determined by U.S. aircraft industry capabilities in their entirety -- not just by decisions about the B-2.

The aircraft industry has been suffering recently from numerous ills: a 70 percent decline in defense sales between 1987 and 1997 (and fewer and fewer new defense aircraft programs); a recent downturn in commercial sales; and aggressive new competitors in foreign markets. Nevertheless, most indicators are positive for the industry's future. Defense sales appear to have reached their low point and commercial and export sales are projected to increase significantly over the next decade. Importantly, the wave of mergers and acquisitions that has involved nearly all major aircraft contractors appears to have strengthened the ability of defense companies to survive. The overcapacity that plagued the industry for many years is being reduced and the aircraft industry is widely acknowledged to be leaner, financially stronger, and more responsive than before. Mutually beneficial teaming arrangements also enable companies to share the risk and build the expertise associated with major new programs. All of the remaining aircraft primes have a full range of aircraft (including bomber) experience and capability, and could potentially support restarted production of the B-2 or the development and production of a new bomber.

From a technology/subsystem perspective, TASC also found that the B-2 is not so unique that the necessary capabilities could not be recreated or retained within the aircraft base. B-2 designs are challenging, but the industrial capabilities that created them were found to be generic. TASC analyzed this question of potentially unique capabilities required by the B-2 in considerable depth, and discussed the study team's aircraft work breakdown structure (WBS) and hypotheses about each WBS element with approximately 200 aircraft industry officials at aircraft primes and major subcontractors. There was a remarkable consensus that there were no major capabilities required for the B-2 that would be lost or that could not be recreated if a restart decision or new bomber go-ahead were given.

This does not suggest that the B-2 was a simple aircraft to build when production began a decade ago, or that it would be any more straightforward to restart in the future. It says only that, once created, the capabilities applied to the B-2 will not disappear from the base and will in some form remain available to the DoD. The process of recreating particular designs -- especially without currently available tooling and know-how -- may be expensive and time-consuming (as the

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present-day B-2 is also expensive and time-consuming), but it would be a process of adaptation, not of discovery.

An examination of some of the more challenging aspects of the B-2 affirms this conclusion. The B-2 pushed stealth technology well beyond its limits when the aircraft was built a decade ago, and the requirement for unaided penetration of heavily defended airspace affects nearly all aspects of its design. The B-2's radar cross section signature requirements can, even today. be met only through extremely precise manufacturing processes and extensive hand-labor on its surface, punctuated by test and retest. Without denying the complexity of these requirements, it is also important to note that stealth technology, which was relatively new a decade ago, has matured significantly in intervening years. Today, stealth is being further advanced by such programs as the Joint Advanced Strike Technology (JAST) program and the F-22. Producing additional B-2s now is not essential to maintaining stealth technology and the ability to apply it to the B-2 or other aircraft. Similarly, the B-2's composite structures are the largest ever produced, but the process basically involves scaling-up conventional composite materials and manufacturing methods. The major items of tooling used to produce the structures are still in place or in layaway and could be maintained until needed again -- in a year or in a decade. Meanwhile, the specialized know-how will be the basis for further advances in composite structures for military or commercial aircraft. The skills necessary to manage the integration of large, complex systems are another capability that is essential to the B-2 (ultimately, managers were brought in from other programs to achieve B-2's success), and there is a question whether the required level of expertise will be sustained by the limited number of very large aerospace programs on the horizon. Although the concern about integration expertise is very real for the DoD and its supporting contractors, procurement of additional B-2s -- a mature system -- will do little to develop or sustain the skill base needed for the future. Finally, the complexity of the B-2's electronics systems cannot be disputed and some technical problems are still being resolved, but the systems themselves are similar to those built by the electronics industry for other military aircraft, and electronics companies that specialize in military aircraft applications will remain viable parts of the base.

In summary, the TASC team concluded that the basic industrial capabilities required for the B-2 are present throughout the aircraft industry and will not be lost if a decision is made to conclude the program at its current strength.

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Restarting the B-2

One possible response to a future requirement to increase the size of the bomber force or make up for attrition or obsolescence is to restart the B-2. A lack of firm data on restart date, delivery schedule, extent of modifications, and other variables made it impossible to perform a full restart analysis, but the project team did explore a variety of restart issues and generated first-order restart costs and schedules.

Although it is uncertain whether more B-2s will be approved in the immediate future, the program is far from being at a halt. For the near-term, capabilities will be supported by final integration and test on the last eight air vehicles (through 1998); upgrades to the final ("Block 30") configuration (through 2000); extensive Program Depot Maintenance (PDM); software upgrades; and other support activities well into the next century. These activities provide a partial base for a B-2 restart, with the specific capability of the base depending on when a go-ahead is given.

The feasibility of restarting a system has been proven in the past; both the C-5 and B-1 were restarted after a several year program hiatus. Interviews with managers involved with both of these restarts stressed the importance of early planning (e.g., tracking of suppliers) and investments in such areas as tooling (both contractor- and government-owned) and potentially long lead items. The B-2 prime contractor, Northrop Grumman, has engaged in "preservation" activities, designed to maintain the readiness of the base while a current procurement decision is pending, and "curtailment" activities that are designed to ensure future operational support of the twenty aircraft in the force within the context of an orderly phase down of the program. However, the contractor has not been funded to prepare for the possibility of restarting the B-2 in the mid- to longer-term.

Preparatory actions for restart are a form of insurance; the cost is relatively small, but it is unnecessary if no possibility of restart is envisioned. But as both the B-1 and C-5 programs amply proved, "enhanced curtailment" offers significant payoffs in time and dollars if restart becomes necessary. In the case of the B-2, uncertainty about the future threat and the response that might be required makes "smart shut down" actions appear to be a prudent investment. These actions can smooth the path to a B-2 restart, if it is ever necessary. However, any actions to enhance restart capabilities for the B-2 must begin soon to ensure that unique tools, equipment, and data owned by contractors are not disposed of, and that government-owned tooling is preserved and protected.

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There are many factors that will eventually be considered as the alternatives of a B-2 restart or new bomber program are weighed. However, an important advantage of restart is the cost and time savings that can be achieved by restarting a relatively mature system, oven initiating a new one. Although a B-2 restart would be a complex undertaking, it could avoid the added investment in R&D that would be necessary in a new bomber program.

Next Generation Bomber

TASC's examination of industry's capability to support longer-term bomber options is termed "next generation bomber." The actual intent of the effort was to assess the adequacy of the technology base to support a future system. Although there are many bomber options available for the future, TASC focused its analysis on a heavy bomber, similar to B-2, that would be a logical follow on to past and present heavy bombers.

Even with trends showing fewer aircraft in development and reduced levels of Government R&D spending, there are important sources of technology for the next generation bomber. For example, JAST is designated an affordability strike aircraft program, but, if maintained at its planned level, JAST will also help to develop and sustain capabilities that are important to bombers. Applicable technology areas being explored by JAST include low observables (LO), propulsion, avionics, and LO maintainability. However, JAST initiatives should be complemented by technology programs that specifically address future bomber requirements. If essential development work does not continue in the absence of an active bomber program, penalties will be paid in terms of program cost and time if and when a new bomber program begins.

The cost estimate for the next generation bomber found in the text highlights the importance of initiating a vigorous affordability program for the next bomber as well as other aircraft types. The baseline estimate reflects TASC's professional judgment of the savings that might be obtained through the implementation of acquisition reform measures, but acquisition reform is clearly not enough to make the new bomber affordable. Efforts must also be made to develop cost-saving manufacturing technologies and design concepts that will radically alter traditional aircraft cost curves. The program to develop more affordable design concepts and manufacturing methods could be carried out in conjunction with JAST or pursued independently, at a relatively modest annual investment. Given our current projection of bomber costs, it is probable that, without an affordability program, no next generation bomber will ultimately be produced.

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Introduction

This report responds to a Congressional request that DoD assess industrial capabilities needed to produce heavy bomber aircraft in the future. An Executive Summary version of this report was forwarded by the Under Secretary of Defense (Acquisition and Technology) to the Congress in July 1995, at which time the Under Secretary indicated that a more detailed final report would be provided in sixty days.

This final report provides a more detailed analysis of industry's capabilities to produce bomber aircraft and expands on findings presented earlier in the Executive Summary. It includes information that could not be included in the Executive Summary, but which is important for a full understanding of industrial capabilities for the B-2.

Copies of this report, as well as the Executive Summary version, are available from:

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Acknowledgments

- **Preparation of this study in a short time was made possible by:**
  - Cooperation, information, and review from throughout the "B-2 community" and especially the B-2 SPO and Northrop Grumman
  - Assistance and support from the sponsor (USD(A&T)) and particularly from the Industrial Capabilities and Assessments office
  - Hands-on involvement from our Senior Advisory Panel, which provided feedback on study direction and progress
  - Dedication of our multi-disciplinary project team, notably:

Don Carson	Kevin Coleman	Steve Curtis
Lois Lembo	Robin Lutz	David Malm
David Olsen	Nate Tupper	Bill Vogt
Paul Winslow		

TASC

Short deadlines for developing interim results and delivering an approved report to Congress could not have been met without the cooperation of many individuals within the Department of Defense (DoD) and industry. In particular, TASC appreciates the outstanding support provided by the Office of the Assistant Secretary for Economic Security (Industrial Capabilities and Assessments), the U.S. Air Force B-2 System Program Office (SPO), and by Northrop Grumman Corporation, the B-2 prime contractor, and the principal B-2 team members, Boeing, Hughes, and Loral. TASC also received superb cooperation from other aircraft producers, including Rockwell, Lockheed Martin, and McDonnell Douglas.

All project activities were guided by an internal Advisory Panel of distinguished experts knowledgeable about bomber aircraft and the aircraft industry. Panel members included Mr. Gordon England, Dr. G. Ronald Fox, Dr. David Lee, Mr. John Stewart, Lt Gen George Sylvester (USAF (Ret)), and Lt Gen William Thurman (USAF(Ret)). Invaluable assistance was also provided by Dr. Jack Gansler, TASC Executive Vice President and long-time expert on the defense industrial base and acquisition issues.

We also acknowledge the important contributions of those who reviewed and commented on earlier versions of our study. Feedback on the Executive Summary has generally been supportive and no significant changes in the original findings or recommendations have been made. However, the project team performed additional analysis and incorporated suggestions made during the outside review of the Executive Summary. Some readers noted, despite their agreement with the report's conclusions, that the Executive Summary may have inadvertently understated the immense difficulties experienced in initially developing and producing the B-2 bomber as well as those that would be faced in either a restart of the B-2 or in the development and production of a next-generation bomber. These are certainly not trivial issues. The complexity of the B-2 and the challenges of future bomber production are fully appreciated by the study team and were a major factor in our analysis. However, the question investigated in this study is whether industry will retain fundamental capabilities to design and produce bombers in the future -- not whether inevitable difficulties will occur or whether costs and schedules might be longer than desired. Without adequate preparation and investments, they certainly would.

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Scope

"... Determine those core bomber industrial capabilities that are needed to maintain the ability to design, develop, and produce bomber aircraft in the near term and in the long term and that .. would take extended periods of time or substantial expense to regenerate, ... and are in imminent danger of being lost"

(FY95 Authorization Act, Section 133(b)(1))

APPROACH

1. **Identify B-2 core industrial capabilities**
   What capabilities are important?
   Are they available in the broad industrial base?
   Will they continue to be in the future?
2. **Assess options, costs and time of potential B-2 restart**
3. **Assess capabilities to design and produce a future bomber**

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This report was prepared in response to a requirement of the Fiscal Year 1995 Defense Authorization and Appropriations Acts, which led the Office of the Secretary of Defense (OSD) to ask TASC Inc. to perform a study of industry's capability to design, develop and produce heavy bombers. The study is the result of a concern on the part of both DoD and Congress that the coming end of B-2 production could affect the nation's ability to produce bombers in the future.

TASC's approach to this requirement involved identifying the core capabilities associated with the B-2 and determining whether these capabilities are dependent on continued B-2 production. TASC also assessed the likelihood that essential bomber capabilities would be retained through other military and commercial aircraft programs, and continue to be available for application in a B-2 restart or a next generation heavy bomber.

The key to our findings is in the word "capabilities", which we defined to include the skills, experience, processes, facilities, technologies, and other factors that enable industry to meet the unique requirements of different aircraft. Although the B-2 possesses a large number of specific designs that are not found elsewhere, it is not these design solutions that are important -- it is the underlying industrial capabilities that created them and could create similar solutions again.

This study complements a prior analysis of bomber requirements, which was performed by the Institute for Defense Analyses (IDA) and submitted to Congress in May 1995. The bomber requirements study found that additional guided munitions would be more cost-effective than additional B-2s in meeting scenario requirements, and that upgrading existing bombers (e.g., B-52, B-1B) was also a more cost-effective option than adding 20 more B-2s to the bomber force. With the requirements study as our foundation, we did not assess the military requirement for more B-2s or speculate on specific missions and characteristics of a next-generation bomber.

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Organization of the Report

- Background
- Methodology
- Core Industrial Capabilities
- Restarting the B-2
- Potential Next-Generation Bomber
- Findings and Recommendations
- Appendices

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The report is organized as follows:

Background on missions traditionally assigned to bombers and evolving industrial capabilities to help meet these needs -- including the needs that ultimately led to design and production of the B-2

Tasks and methods used in different facets of the study

Results of our analysis of **core industrial capabilities** for the B-2, including answers to the questions posed by Congress. This section addresses both the current and forecast status of the nation's aircraft industry and the "uniqueness" of specific capabilities required to produce the B-2

Assessment of industry's capability to **restart the B-2** if required to do so in the future (year 2000 and beyond) and the identification of shut-down actions that could reduce restart costs and time

Assessment of factors that affect industry's ability to **produce a future bomber,** including the availability of technology and the continuation of military aircraft programs that will help to retain capabilities over the mid- to long-term

A summary of **findings and recommendations**

Appendices, which contain detailed descriptions of the cost estimating methodology (Appendix A) and a list of study references (Appendix B).

Background

This section provides background information on how the B-2 evolved from previous U.S. heavy bombers, and where the B-2 program stands today.

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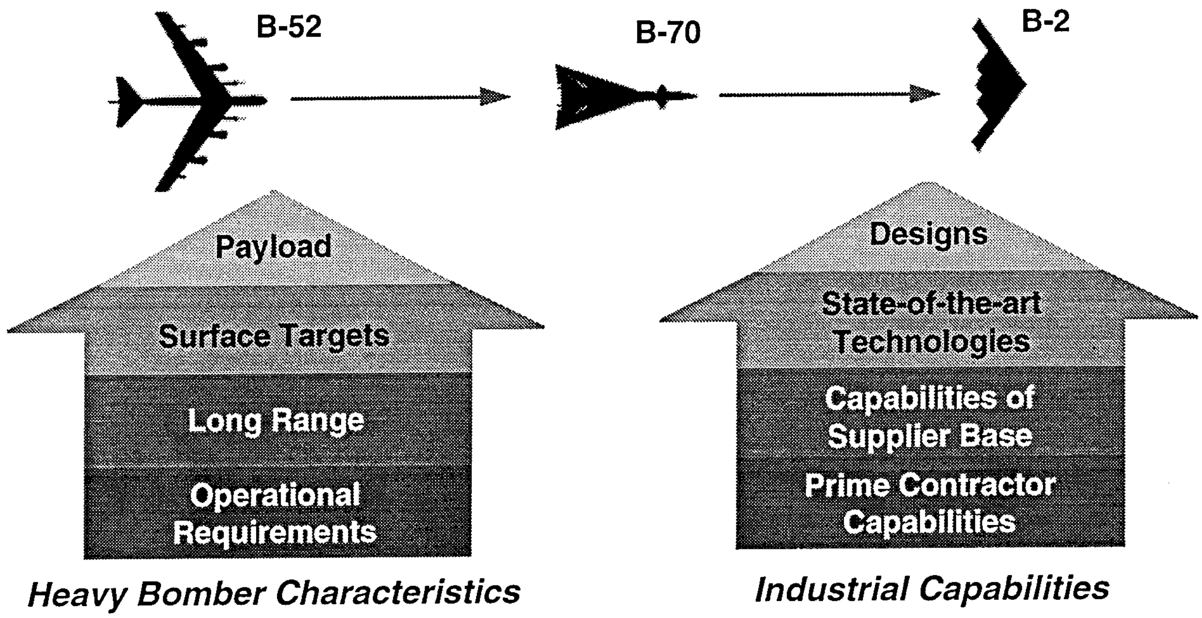
What is a Bomber?



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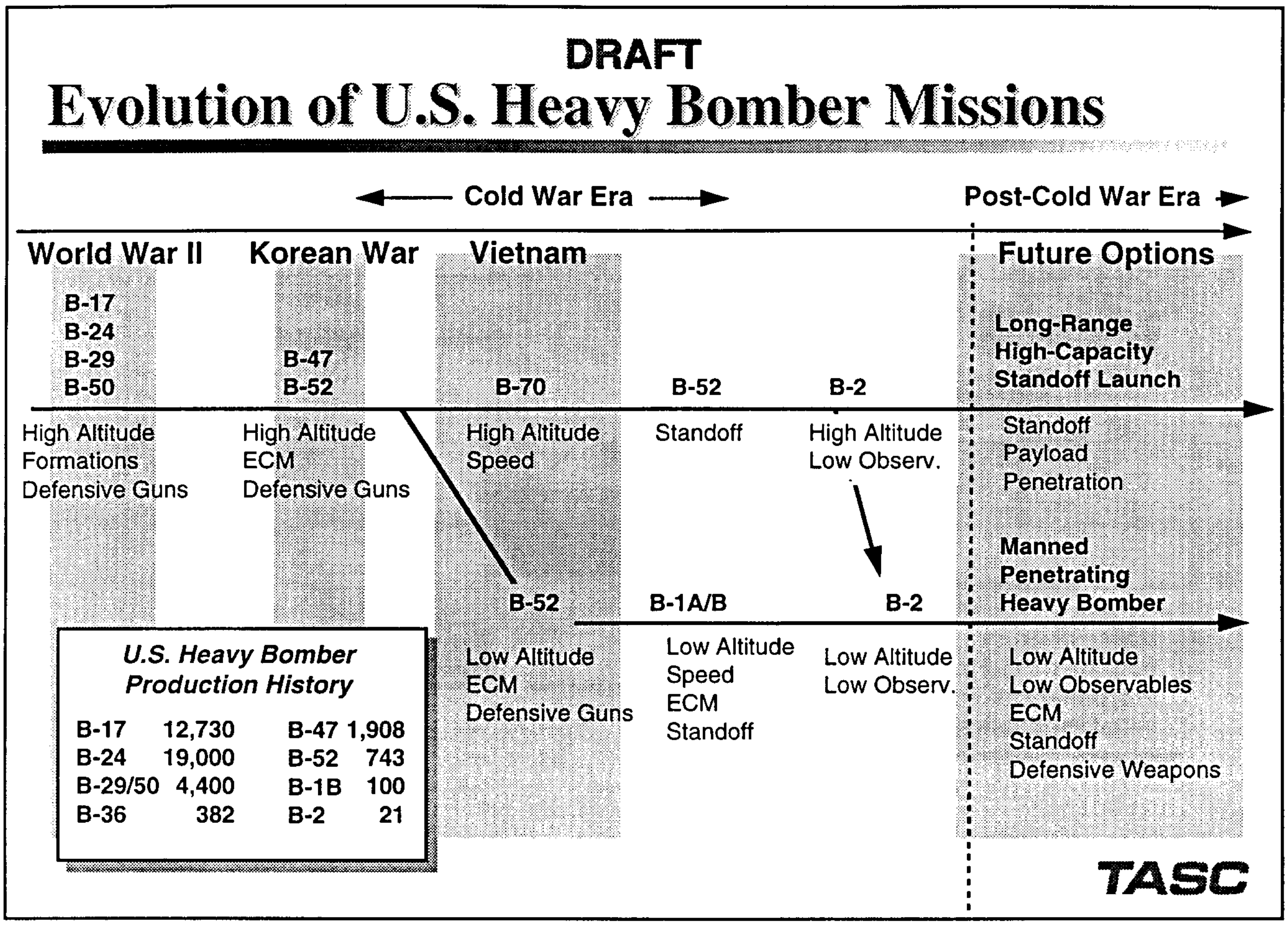
The Congressional requirement for this study specifically concerned industrial capabilities for the B-2 and other heavy bombers. For study purposes, a heavy bomber is defined as one capable of delivering large weapon payloads against surface targets at long range. The principal challenge for bomber force operators has been to find the combination of design features and operational concepts that permit these relatively large and marginally maneuverable aircraft to penetrate enemy air defenses, deliver their payloads, and return in sufficient numbers to justify the investment in them. Bomber evolution has, to a large degree, been a race to stay ahead of opposing air defense technologies.

Heavy bombers have been an important component of the U.S. aircraft inventory for over fifty years, and, in many ways, the B-2 is the culmination of bomber evolution. From the end of World War II, every fielded U.S. bomber design has had its origin in a mission to penetrate Soviet air defenses and deliver nuclear weapons. As a wider selection of conventional weapons has become available, bombers have assumed a larger set of conventional missions against a more varied range of targets.

The use of bombers in the past illustrates the diverse missions of these aircraft. During World War II, bombers were used in mass formation, dropping large numbers of unguided bombs on fixed area targets such as industrial complexes or transportation nodes, and, occasionally, enemy forces in the field. Bombers ended the war in a campaign of incendiary attacks, where the targets were entire Japanese cities. During the Korean and Vietnam conflicts, bombers continued large-scale employment of iron bombs in raids designed to disrupt the flow of enemy forces into battle areas.

As technology evolves, the capability of bombers to deliver precision conventional weapons against numerous fixed and mobile aimpoints during a single sortie will be enhanced to the point that the old "tons on target" mentality that has dominated bomber operations for so long will be almost completely supplanted. It is very likely that the bomber of the future will be, predominantly, a global precision strike platform.



The U.S. Army Air Corps pioneered the doctrine of daylight precision bombardment, and built a fleet of heavy bombers during World War II to implement it. The numbers are, by today's standards, staggering: over 36,000 heavy bombers (B-17s, B-24s, and B-29s) produced in about six years to sustain massed raids in multiple theaters, and to offset combat losses, which were fully one-third of the total manufactured.

The advent of nuclear weapons eliminated the requirement for massed formations, but the early Cold War designs (B-36, B-47, and B-52) all relied on altitude and active defenses to penetrate Soviet airspace. However, by the late 1950s the only remaining heavy bomber was the B-52, and its employment had evolved to low-altitude penetration in light of rapidly improving Soviet air defenses. The B-70 was an attempt to resurrect the high-altitude penetration mode, but it foundered on the shoals of affordability. During the Vietnam conflict, some B-52s were assigned to high-altitude conventional bombing, but most, with steadily improving airframe and avionics, were retained for the low- altitude role.

From the mid-1970s, some B-52s were assigned a third mission: cruise missile carrier. None of these employment modes figured in the original design concepts, underscoring a key consideration in defining a next-generation bomber and potential employment of the B-2: long-lived heavy bomber designs will be assigned new missions and will be used in "unorthodox" ways to solve unanticipated operational problems or take advantage of new technological developments.

Mission adaptability has also been true of the B-1, which began life as the follow-on to the B-52 for the low-altitude strategic penetrator mission. It soon became clear that the fielded B-1B would be employed principally for, and is being upgraded to conduct, conventional missions. Like the B-52, the B-1B is fitted for cruise missiles, a capability that did not figure in its original design concepts.

The B-2 was originally intended for high-altitude strategic penetration of Soviet defenses. This changed to low-altitude penetration during the design phase to increase survivability. Like its predecessors, the B-2 was originally intended as a nuclear weapons delivery platform, and conventional capability is being added to meet post-Cold War needs.

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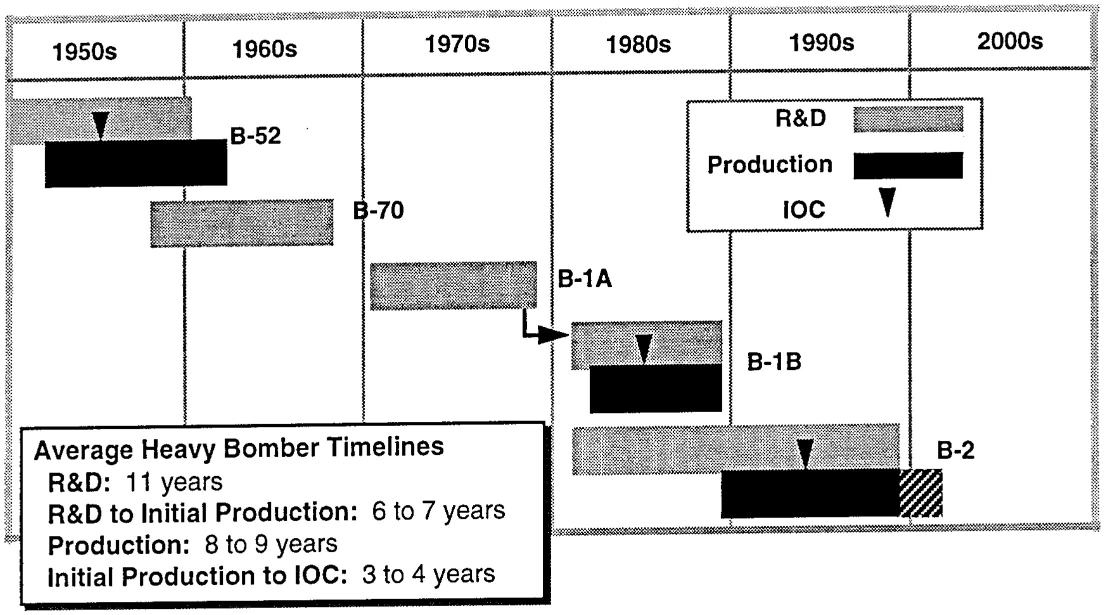
Heavy Bomber Production Timelines



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This chart depicts R&D and production timelines for almost 50 years of heavy bombers. Not surprisingly, the numbers of production aircraft have fallen dramatically since World War II and the Korean War, as the need for large fleets of heavy bombers has diminished and the technology content and cost of these aircraft has escalated. The currently planned fleet of 20 B-2s, although technologically sophisticated and capable of carrying out a mission that could not have been envisioned 20 or 30 years ago, is a "different beast" from the 743 production B-52s that have been the mainstay of our bomber force since the Korean War. Nevertheless, the two aircraft are evolutionary developments in the history of U.S. heavy bomber design and production.

With the exception of small gaps between the B-70 and B-1A programs and between the B-1A and B-1B and B-2 programs, heavy bomber R&D has been continuous since 1950, advancing the state-of-the-art as Soviet defenses have grown in sophistication. Average duration of the five heavy bomber R&D efforts has been 11 years. Average duration of the three heavy bomber production programs has been between eight and nine years. If the B-1A is included as R&D leading to the B-1B, the average duration of R&D prior to production for the three heavy bombers produced is between six and seven years. Given initial operating capability (IOC) dates of 1955 for the B-52, 1985 for the B-1B, and 1994 for the B-2, the average period between initiation of production and IOC is between three and four years.

However, it is noteworthy that there have traditionally been long gaps between the production of one bomber and its successor. These production gaps did not erode ultimate capabilities once a subsequent production decision was made.

The timelines associated with heavy bomber R&D and production are certainly indicative of the technological sophistication of these aircraft. Both the B-70 and the B-1 represented technology "leaps." The B-2 represents an even greater leap, as indicated by the still ongoing R&D timeline. Many casual observers of the military aircraft industry are unaware of the magnitude of the continuing R&D program for the B-2, which has been a largely "concurrent" program since the start of production.

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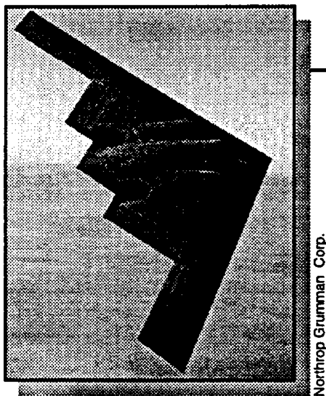
B-2 History



TECHNICAL DATA

Key Components

Airframe: Composite Flying wing
Propulsion: GE F-118-GE-110 turbofans (mounted in pairs within wing structure)
Avionics
Defensive Systems
Offensive Systems

Dimensions

Length: 69 feet
Wing Span: 172 feet
Height: 17 feet
Empty weight: 110,000 pounds
Maximum weight: 400,000 pounds

Performance Characteristics

Payload: 50,000 pounds
Range: 7,600 miles
Service ceiling: 50,000 feet
Crew size: 2-3

TASC

The B-2 grew out of stealth technologies that emerged in the 1970s, and extended those technologies in terms of platform size, pervasiveness of "stealthy" features, and extent of stealth characteristics both designed in and achieved in operational tests. President Carter released the aircraft from its virtually complete secrecy when he revealed the existence of an Advanced Technology Bomber in 1980. A year later, the Air Force announced its requirement for a highly survivable, penetrating strategic bomber to ultimately replace the B-1B. The B-2's extremely challenging performance goals and use of state-of-the-art stealth technology have shaped it as an expensive aircraft since its R&D phase.

There is no doubt that the B-2 is the most complex and technologically advanced aircraft ever produced in the U.S., in terms both of its performance goals and of the innovative design and manufacturing methods devised to achieve them. Although initial feedback from the aircraft's operators has been positive, the future of this technological marvel is uncertain. The B-2 is also the most costly aircraft ever produced, consuming what many defense analysts view as a disproportionate share of defense resources to achieve Cold War missions whose priority and likelihood have diminished. Conceived when the Soviet threat was the greatest menace facing the United States, the B-2 became operational in a post-Cold War era involving lesser and more diffuse contingencies.

Because of its large size, limited flexibility, limited conventional capability, and high target value, the B-2 contributes less in regional contingencies than it does in strategic missions. A recent DoD analysis of future bomber force requirements found that the B-2 was not as effective as other bombers (e.g., the B-52H and B-1B) in responding to regional threats. Further, the Bomber Requirements study concluded that precision guided munitions (PGMs) and conventional attack upgrades to existing bombers are higher investment priorities than additional B-2s. DoD's 1993 Bottom-up Review similarly found that the requirements of two Major Regional Conflicts (MRCs) could be met without additional B-2s. Issues surrounding the aircraft's cost-effectiveness led to a 1992 Congressional decision to "cap" B-2 production at 21 aircraft, and have led the DoD to oppose lifting that cap to allow production of more B-2s.

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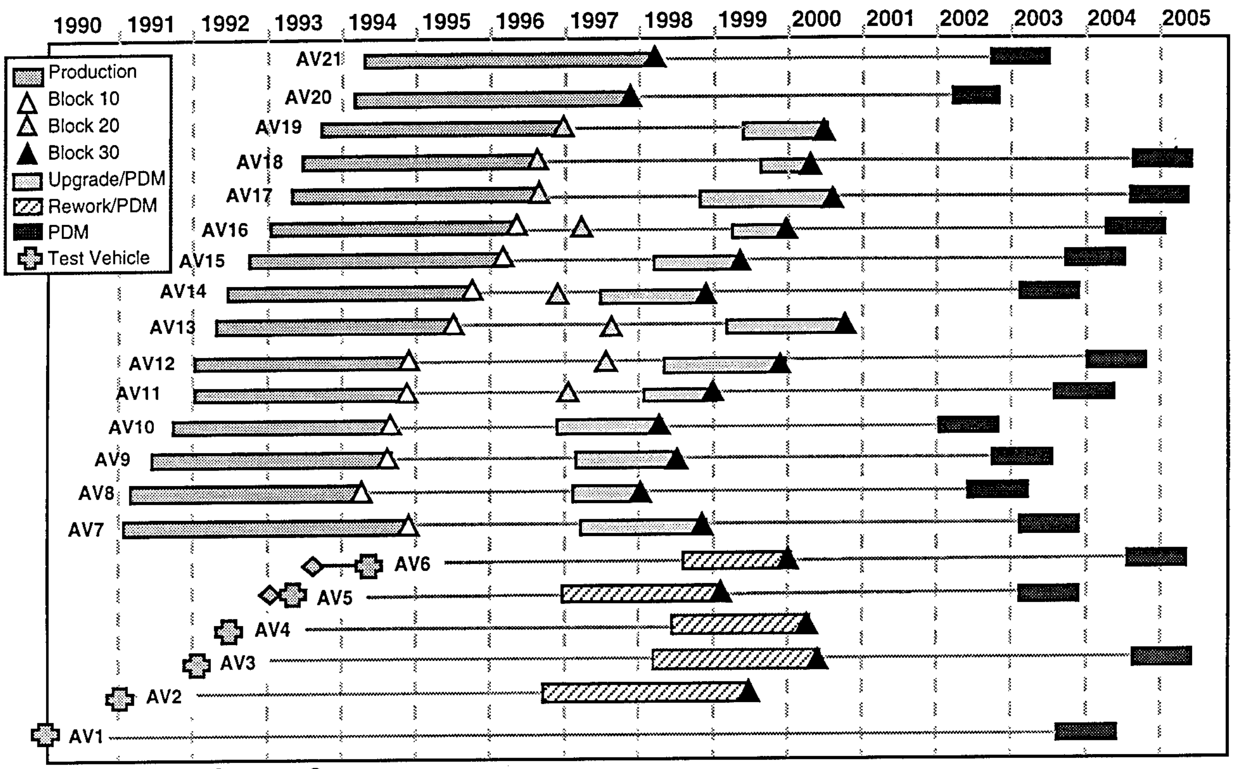
Delivery Schedule for 21 B-2s



Source: Northrop Grumman Corp.

In 1980, Northrop was awarded a Full Scale Development contract for a new bomber with the expectation that 132 would be produced by the 1990s. Three major redesign efforts occurred during the aircraft's development phase -- one major redesign to accommodate revised loads and performance criteria, another to replace aluminum in the wing with graphite composite, and another to modify the wing center section to add low-level penetration capability. The latter design change alone resulted in a one-year schedule slip and an added cost of $1 billion.

After the low-rate initial production (LRIP) award in 1988, the first B-2 rolled out of Northrop's Palmdale, California, facility in November 1989. Shortly afterward, as a result of a major aircraft review by DoD, the B-2 buy was cut from 132 to 75. Procurement was again reduced -- to only 20 -- as part of reductions in the FY93 defense budget. These reductions have had a tremendous impact on B-2 costs, as well as contractor investments in manufacturing technology, facilities, and personnel. Investments such as the multi-million dollar integrated machining system at Vought went unused as production levels dropped below the minimum levels required to sustain automated systems.

The first operational B-2 was delivered to the Air Force in December 1993. The currently approved program includes 21 B-2 aircraft -- six development aircraft (five of which will be reworked and delivered as operational B-2s) and 15 production aircraft. One of the developmental B-2s (AV-1) was not produced as a full-up aircraft and will not enter the Air Force inventory. The B-2s are being delivered in three configurations (called "blocks"), with each block representing increasing capability. The third ("Block 30") configuration includes full PGM capability, full low-observable performance, fully operational defensive and offensive avionics, additional modes for the synthetic aperture radar (SAR), and a more sophisticated mission planning system. All aircraft will be Block 30-capable by the year 2001.

Although no further block upgrades have been approved for the B-2, experience with previous systems has caused many observers to suggest that such upgrades are highly likely. As a minimum, we would expect future upgrades to the radar, Defensive Management System (DMS), and the engines, similar to what has been done on other modern aircraft programs.

Methodology

This section provides details of the methodology that TASC followed in conducting this industrial assessment of the B-2.

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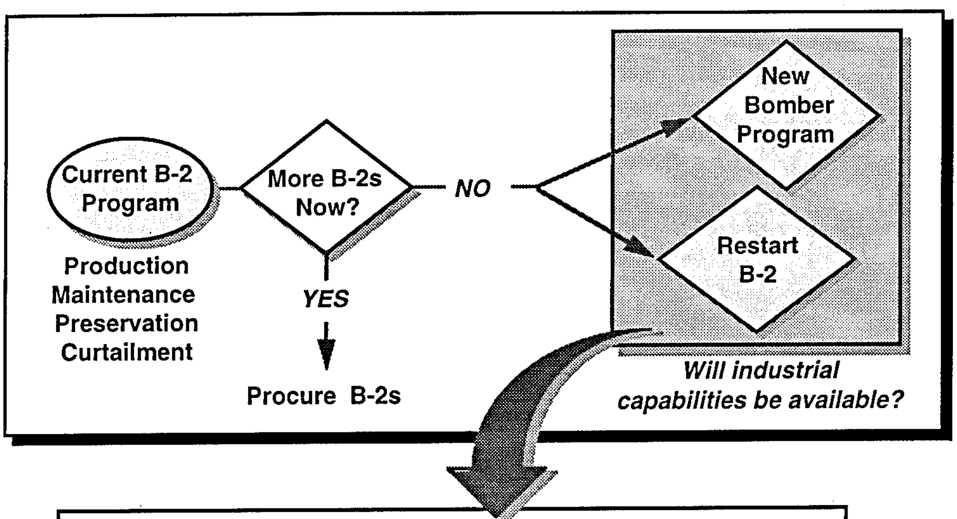
Approach



- Survey of aircraft industry capabilities
- Engineering comparisons (B-2 / other military aircraft)
- Analysis of aircraft industry trends (sales and manpower)
- Cost/schedule/risk analysis of B-2 restart and new bomber
- Case studies of past military aircraft program restarts

TASC

This graphic illustrates TASC's approach. Rather than analyzing current B-2 capabilities and industry's ability to support the production of additional aircraft in the near term, TASC took a somewhat longer view. This study is especially concerned with whether capabilities will continue to be available if the B-2 program ends, and whether industry will be able to respond to a post-2000 decision to restart B-2 or design, develop, and produce a next generation bomber.

Some of the methods used in the analysis are shown on the graphic. TASC's approach involved three tasks. The first was to identify the core industrial capabilities associated with heavy bombers and determine whether these capabilities are dependent on continued B-2 production. This task also assessed the likelihood that essential capabilities would be retained through their application to other military and commercial aircraft programs. The remaining tasks examined the aircraft industry's ability to restart the B-2 or initiate a new bomber program when required. These study tasks will be described in more detail in the following pages.

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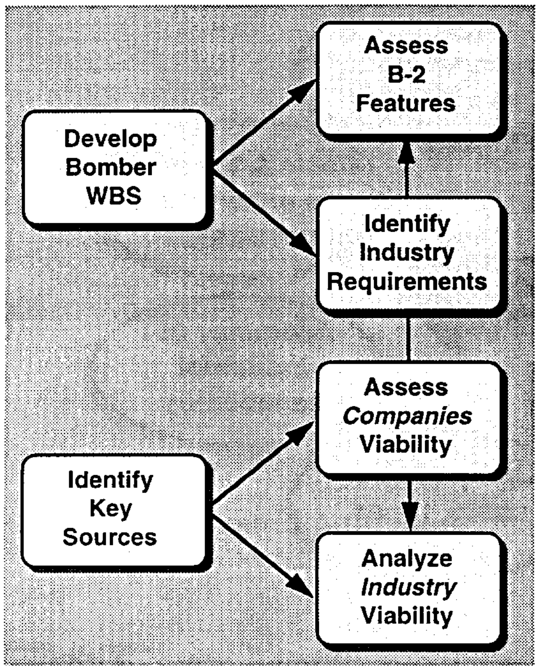
Task 1: Assess Core Industrial Capabilities

Activities ◄——► Information Sources



Site Visits Completed:

B-2 SPO	Dayton, OH
Northrop Grumman	Pico Rivera, CA
Northrop Grumman	Palmdale, CA
Rockwell	Palmdale, CA
Lockheed Adv Dev	Palmdale, CA
Boeing	Seattle, WA
McDonnell Douglas	St. Louis, MO
McDonnell Douglas	Long Beach, CA
Lockheed Martin	Marietta, GA
Northrop/Vought	Grand Prairie, TX
AF Cost Library	Dayton, OH
Hughes	El Segundo, CA
Loral	Owego, NY
General Electric	Evendale, OH
F-22 SPO	Dayton, OH
JAST Program	Washington DC

TASC

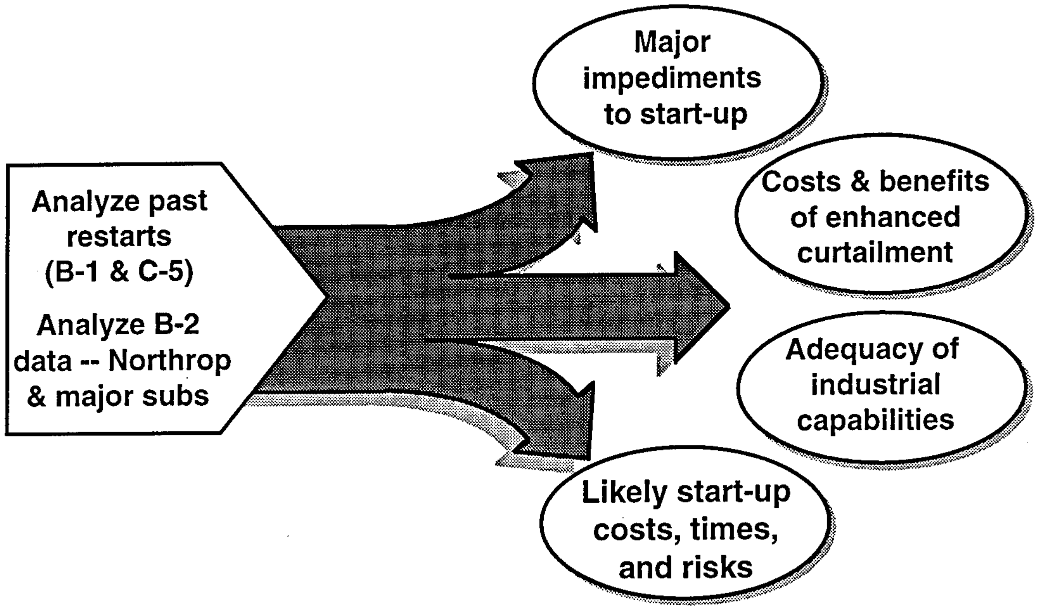
TASC applied a variety of methods to identify core industrial capabilities required by the B-2 and to assess the aircraft industry's ability to produce a bomber in the future.

First, the study drew on the expertise of approximately 200 senior representatives of aircraft prime and subcontractors and government organizations concerned with aircraft technologies. The team visited the locations listed on the chart, including Northrop Grumman (the B-2 prime), major B-2 subcontractors, and the B-2 SPO. Each site visit involved one or two days of structured discussions about specific industrial requirements and capabilities in each area of an aircraft Work Breakdown Structure (WBS), which was developed by the study team (see page 30 of this report). Interview topics included the complexity of manufacturing processes for each element, the identity and viability of current and potential sources, and unique aspects of the B-2 as compared to other aircraft. Additional information was gathered through written questionnaires to each company, discussions with personnel at the B-2 SPO, a review of the many analyses that have been performed on different facets of the B-2 (see Appendix B), and a review of the pertinent technical literature. Discussions were also held at the Joint Advanced Strike Technology (JAST) program office and the F-22 SPO to better understand technology developments that could contribute to a future bomber.

Following the data collection phase, the team compared B-2 design solutions to those of other aircraft to identify significant differences in the capabilities required for design and production. Experts worked with the team to assess the impact of differences in scale, maturity and complexity between the B-2 and other aircraft. This engineering analysis was complemented by an economic analysis of the aircraft industry and financial analyses of key contractors responsible for important parts of the B-2. The financial assessment in part involved an analysis of the markets of suppliers that contributed more than 0.1 percent to the cost of the B-2, and which were identified by Northrop Grumman and its major subcontractors (Boeing and Vought) as particularly critical to their effort. The economic analysis included sales and manpower forecasts for the aircraft industry as a whole and for important segments. Industry dynamics (e.g., export sales growth, restructuring, etc.) that could influence the future outlook for producing a B-2 or B-2-like aircraft were also analyzed. (This part of the analysis is presented on pages 18-41.)

DRAFT

Task 2: Analyze B-2 Restart Issues



TASC

Any analysis of a B-2 restart is, by necessity, hypothetical -- there are no current plans for restarting the program and the timing, duration, rationale and other important variables affecting industry's responsiveness to a restart decision are undetermined. Faced with so many unknowns, TASC initially focused on the simple feasibility of restarting the B-2 at an unspecified future date after the production base had grown cold. For cost-estimating purposes, a go-ahead in the year 2000 was assumed.

One study technique involved case studies of the restart of the C-5 and B-1, as well as industry's ability to accommodate interruptions in production for the P-3 and U-2. Although these program histories may not be directly applicable to a potential B-2 restart, the case studies yielded "lessons learned" that provide insight into factors that could affect B-2 restart times and costs. The case studies entailed visits to companies where restart occurred and discussions with corporate executives and other individuals who were personally involved in restart activities.

One simple observation is that the greater the time lapse between current program completion and restart, the greater the difficulty (and cost) of restarting a program. The extent to which preparations are made for a potential restart will also be a major influence on cost and time. For example, careful preservation and lay-away of major tooling items could have a significant impact on the cost and lead-times encountered.

The team also developed independent cost, schedule, and risk estimates for restart options. Previous estimates of a B-2 "restart" (i.e., Northrop Grumman, the Air Force, the OSD Cost Analysis Improvement Group (CAIG), and IDA) have assumed that a decision to resume or restart B-2 production would be made in the near-term (i.e., FY97). However, a restart may be a more plausible requirement further into the future, when different threats that call for B-2 capabilities might emerge. As a result, TASC's estimates assumed a restart in the post-2000 time frame.

The restart analysis is presented on pages 42-60.

DRAFT

Task 3: Assess Capabilities for a New Bomber

Explore historical applications and forecast future heavy bomber concepts	*Identification of heavy bomber characteristics that might apply to a next-generation bomber*
Review R&D budgets & thrusts (particularly F-22 and JAST)	*Identification of critical aircraft technologies that could affect the future design and production of a B-2-like bomber*
Assess impacts of emerging technologies on future bomber	*Determination of whether and how emerging technologies may affect B-2 components and industrial requirements (including start-up)*

TASC

Any discussion of a "next-generation bomber" is also, by necessity, speculative. Given the missions that a "bomber" might conceivably be assigned in the future, the threats that might emerge, the budgetary constraints faced by DoD, and the new technologies that might be available two decades from now, the characteristics of a new bomber could range from those of a system similar to the B-2 to a less technologically sophisticated platform for a new conventional standoff missile. Bomber options along this spectrum would stress industrial capabilities in different ways. At the extreme, the standoff platform could require few of the stealth-driven B-2 industrial capabilities described elsewhere in this report.

Since it was infeasible to analyze the next-generation bomber with any degree of precision, this task focused on examining those aspects of a future bomber that are most likely to stress industrial capabilities. In particular, heavy bomber characteristics were loosely defined, the costs associated with such a heavy bomber were estimated (using both traditional and "affordable" acquisition approaches), and a comparison was made between a new bomber and a "restarted" B-2 to identify the penalties associated with beginning a new program "from the ground up."

Perhaps more importantly, the task involved a review of design and production capabilities that could be expected to be available in the post-2000 time frame and assessed their adequacy in meeting next-generation bomber requirements. Special attention was paid to technologies that are currently being developed by the F-22 and JAST programs, as well as other national R&D efforts.

The results of the analysis of a next-generation bomber can be found on pages 61-71.

DRAFT

Definitions

- **Heavy bomber --** Aircraft that have mission requirements of long unrefueled range, heavy weapons load, and unaided penetration of enemy airspace. Specific heavy bombers differ in terms of means of penetration, defensive measures, and payload
- **Point design or design solution --** Specific (and probably unique) design solutions associated with any particular aircraft -- including the B-2. Designs will inevitably differ between each aircraft, but specialized capabilities are not necessarily required to implement the different designs
- **Capabilities --** The basic, underlying skills, processes, facilities, experience, technologies and other resources that enable industry to implement point designs. All capabilities required to design and produce an aircraft are considered essential to that aircraft. Industrial capabilities are the chief concern of this study
- **Unique B-2 industrial capabilities --** Manufacturing capabilities that are required only for the B-2 and are not widely available outside the B-2 contractor base. Loss of unique capabilities could potentially cause obstacles in restarting the B-2 or producing a similar bomber in the future
- **Other terms** are used in specific ways within the context of this study, but are not as wide-reaching as the above.

TASC

Early in the project, the study team found that a set of definitions and assumptions was needed to bound the analysis and ensure that all activities were guided by the same principles.

The most important of the definitions is that of "capabilities," which we define to include the basic, underlying skills, processes, facilities, technologies and other resources that enable industry to meet particular requirements of different aircraft. A capability can be applied to different designs. Numerous capabilities that existed in the aircraft industry prior to the start of the B-2 program were used to develop and produce the B-2. Without this definition, one could argue that everything about the B-2 is unique, since B-2-specific "design solutions" are not found on other aircraft. However, from an industrial base perspective, it is not these specific design features that are important -- it is the underlying industrial capabilities that created them and potentially could create similar solutions again.

The four definitions presented in the chart are intrinsic to our methodology and helped to shape the study findings. The "other" category includes additional terms that are important to understanding specific parts of this study. For example, two terms that have been frequently confused are B-2 "preservation" and "curtailment" activities. They are not synonymous, as many believe. B-2 **preservation** refers specifically to an FY95 appropriation of $125 million (only partially released to date) for the express purpose of preserving the B-2 team's ability to continue/restart B-2 production in FY97. It is intended as an interim measure pending an FY96 decision on the current program cap. By contrast, **curtailment** is directed toward the orderly close-out of the current B-2 production base, while assuring the capability to sustain the planned fleet of 21 bombers. These activities were initiated when the program was reduced from 75 to only 20 aircraft in 1992.

Still other terms that need to be understood include enhanced curtailment (also referred to as "smart shut-down"), low observables technologies and materials (LOT and LOM), WBS, government- and contractor-owned tooling, lay-away, and others. These are defined at appropriate points in the report.

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Assumptions

- **Study is focused on impact of B-2 termination on industrial capabilities for bombers**
  - Study is **not** concerned with bomber requirements (examined in prior DoD study)
- **Must make reasonable assumptions to deal with uncertainties, e.g.,**
  - Circumstances, timing and urgency of B-2 restart
  - Changes in structure and capabilities of aircraft industry (commercial and military)
  - Continuation of F-22 and JAST, and ability of programs to sustain and advance bomber-related technology
  - Nature and timing of potential next-generation heavy bomber
  - Impact of acquisition reform and affordability measures on future aircraft cost and schedule
- **Specific assumptions are defined under major report topics**

TASC

Just as it is important to develop definitions early on, so is it important to explicitly state the assumptions that underlie the study. Our assumptions permeated all aspects of the work, touching on our perceptions of heavy bombers and the timing and conditions of a B-2 restart or next-generation bomber program. Other fundamental assumptions concern the degree of flexibility that can be shown by important vendors and the likelihood that today's healthy supplier will be available to participate in bomber programs tomorrow.

The first assumption reiterates the focus of the study -- B-2 industrial capabilities only. We did not examine requirements, addressed in a separate and earlier study, which concluded that there is no compelling requirement for additional B-2 bombers at this time.

In many areas, specific assumptions were necessary in order to limit the investigation. Without such limitation, the range of possibilities becomes virtually infinite and provides no foundation on which assessments can be built. Specific assumptions that provide the necessary structure are stated in the appropriate parts of this report.

Core Industrial Capabilities

- The "Bomber Industry"
- Special Features of the B-2

This section reports on the project's first task, which defined core industrial capabilities required by the B-2 and assessed the likelihood that those capabilities will remain in industry if the B-2 is not continued. Since "bomber capabilities" are but a subset of broader aircraft industry capabilities, we first assessed the nature of the so-called "bomber industry" and then examined the economic outlook of the broader aircraft industry.

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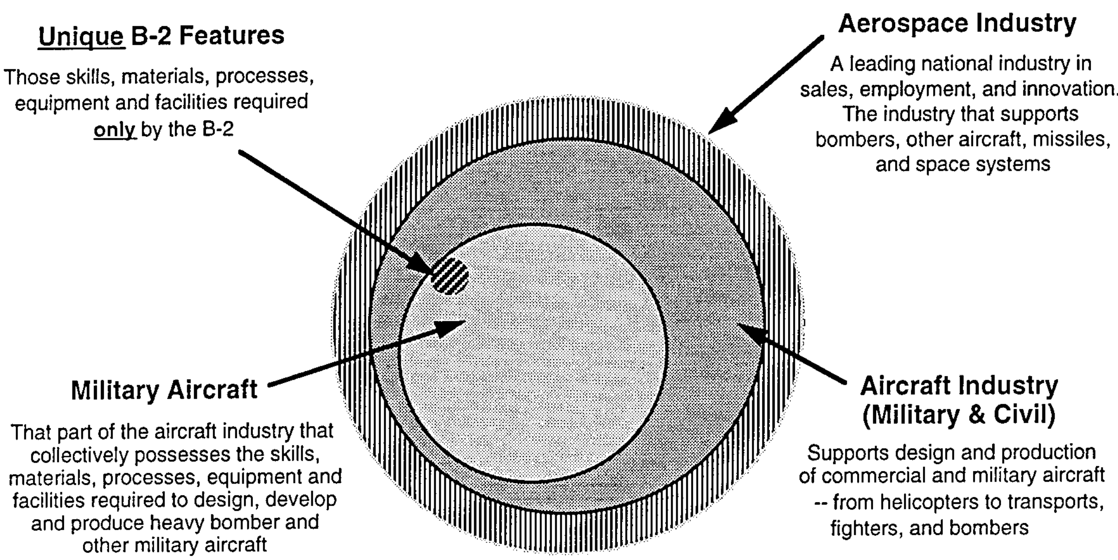
B-2 Draws From Broad Industry Capabilities



Note: Not to scale

TASC

There is no distinct "bomber industrial base." Although a specific team of firms is responsible for developing and producing a particular bomber at a particular time, the team is dissolved when the program ends, and a new and different team is likely to be created to support the next generation of bomber. The intermittent nature of bomber programs could not support a dedicated base, even if one made sense on other grounds. **This broad view of the "bomber industry" directs this study not only to the firms that supply (or did supply) the B-2, but to a much larger set of companies that produce similar components for aircraft of all kinds.**

This chart shows how the B-2, with its unique features, fits into the broader array of industrial capabilities for aircraft. In a counter clockwise direction, the B-2 program is a small part of the nation's aerospace industry. This includes not only fixed wing aircraft producers, but also those that develop and produce such products as helicopters, rockets, missiles, and space systems. Overall, the nation's aerospace industry is immense, with annual sales of over $100 billion (1993). The aircraft industry is the largest segment within aerospace, with 1993 sales well over $50 billion. To illustrate the size of this industry, the B-2 accounted for just a few percent of aircraft industry sales at the program's 1989 peak. Although the civil and military segments of the aircraft industry are generally viewed as distinct, there is considerable overlap between the two markets. For example, Lockheed Martin has produced commercial aircraft, but is also developing (with Boeing) the Tier III unmanned aerial vehicle and has produced the SR-71 (the nation's fastest operational aircraft), the C-5 (the nation's largest operational aircraft), and the F-117 (the nation's first stealthy aircraft).

Aircraft companies produce aircraft -- many different types of aircraft. The aircraft industry now includes only four companies with prime contractor capabilities: Boeing, Lockheed Martin, McDonnell Douglas, and Northrop Grumman. Rockwell also has been an important prime in the past, and retains the capability. These companies regularly team with each other in constantly changing patterns on different commercial and military programs.

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Sources of Unique Aircraft Characteristics

Aircraft Industry Capabilities

WBS \ Ind. Cap.	Design	Mfg	Mtls & Proc'es	Soft-ware	Pgm Mgt Sys Engr
Airframe	●	●	●	N/A	●
Propulsion	●	●	●	●	●
Electronics	●	○	●	●	○
Subsyst's	●	●	●	●	○

Military Aircraft Industry Capabilities

WBS \ Ind. Cap.	Design	Mfg	Mtls & Proc'es	Soft-ware	Pgm Mgt Sys Engr
Airframe	●	○	●	N/A	○
Propulsion	○	○	○	○	○
Electronics	○	○	○	●	○
Subsyst's	○	○	○	●	○

Heavy Bomber Products

WBS \ Ind. Cap.	Design	Mfg	Mtls & Proc'es	Soft-ware	Pgm Mgt Sys Engr
Airframe	○	○	○	N/A	○
Propulsion	○	○	○	○	○
Electronics	○	○	○	○	○
Subsyst's	○	○	○	○	○

Key

● Unique to Segment

○ Generic Applicability

TASC

This chart provides a different perspective -- one that requires explanation -- on the role of the aircraft industry (vice "bomber industry") in supporting B-2 and future bomber development and production. In progression, the shading of the circles indicates the degree of "uniqueness" of the capabilities of that sector from the next higher level of industrial aggregation (i.e., bomber products --> industrial capability for military aircraft --> industrial capability for all aircraft --> industrial capability for aerospace products --> industrial capability for manufacturing). One can conclude that the aircraft industry is very different from other industries (such as automotive) and, consequently, possesses a large number of unique attributes. In contrast, the heavy bomber industry has much in common with other aircraft industry segments, and very little that can truly be called "unique."

This chart, derived from expert opinion, indicates that the capabilities required for heavy bombers are not unique. Rather, producers and suppliers of bomber components have developed their B-2 related capabilities through their involvement in a more extensive aircraft program environment. If these capabilities were needed for a future bomber, it would be necessary to look toward capabilities that are resident in the aircraft or aerospace base -- not toward a more distinct set of contractors that are chiefly associated with bomber production.

Somewhat more of the unique capabilities are associated with the military aircraft industry, and are not relevant to commercial aircraft. Examples include design capabilities for high-performance military aircraft and specialized software.

However, the vast majority of unique bomber capabilities are found in the aerospace or aircraft industry as a whole. These capabilities originally might be developed for specific applications, but are later applied to a wide variety of military and commercial aircraft.

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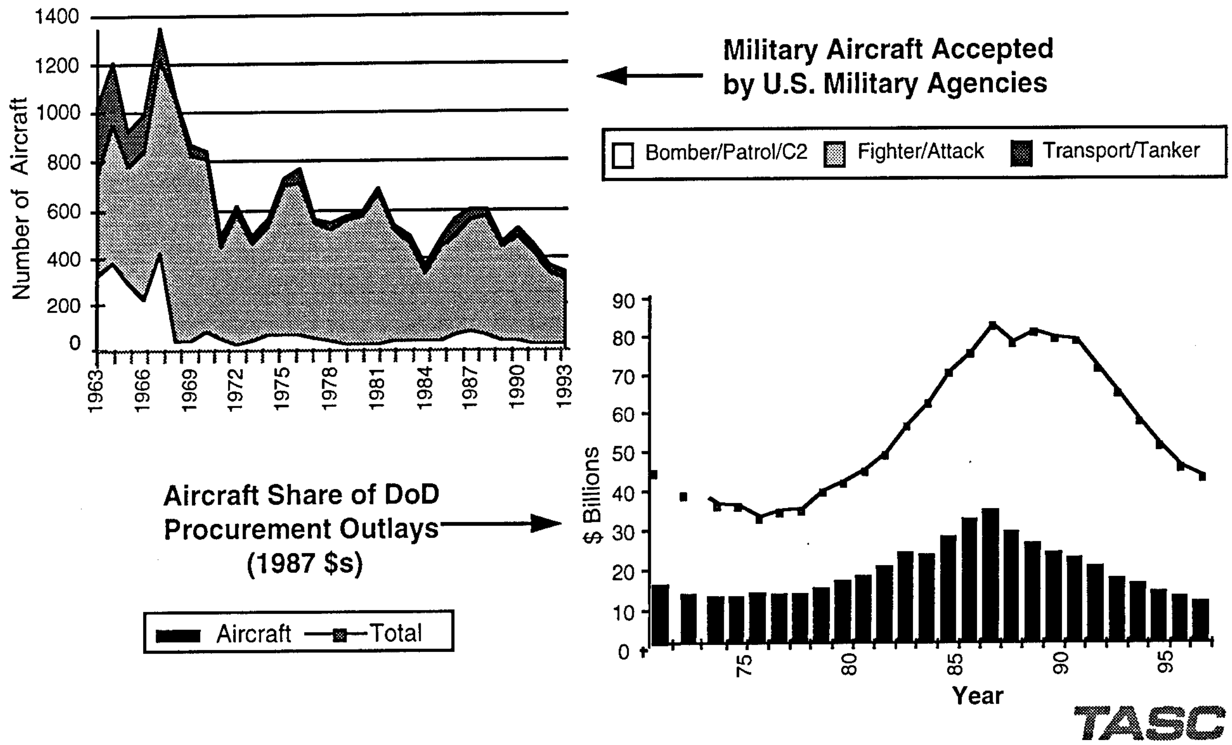
Military Aircraft Procurement Trends



The bomber's role as an important product of the aircraft industry means that essential bomber capabilities are inextricably linked to the industry's future health.

As the chart on the left shows, the number of aircraft accepted by DoD has been relatively erratic over the past thirty years as various procurement programs begin, reach their peak, and end. However, the overall trend has been downward over the last three decades as aircraft costs have increased. Deliveries peaked at about 1,350 new airplanes per year in 1967, and have declined to fewer than 400 per year today. Except for deliveries of up to 400 bomber and patrol aircraft (chiefly B-52s) annually during the mid-1960s, bombers have constituted a very small percentage of deliveries throughout this period.

The second chart provides information on the aircraft share of DoD's procurement budget. From the standpoint of dollars (outlays), the procurement budget for aircraft reached its peak in the mid-1980s. By 1997, DoD aircraft procurement will be down approximately 70 percent from its 1987 level, but **significant increases in military aircraft procurement are projected to give the industry a fresh infusion of military sales between 1997 and 2000.**

The aircraft share of the DoD procurement budget has been relatively constant over the 25-year period, reaching about 40 percent during the peak years of the 1980s and remaining at about 30 percent during the 1990s.

Overall, reductions in the absolute level and share of DoD procurement have had a major impact on the industry. One result has been a reduced dependence on military sales and a greater focus on the more promising civil transport and export segments. The military portion of aircraft sales has declined from approximately 80 percent in the mid-1980s to less than 50 percent today. At the same time, exports and commercial sales are forecast to increase by about 40 percent annually between 1997 (the industry's low point) and 2000. Growth of these segments is projected to be even higher in the 2000 to 2010 time period. As these changes are realized, the nation's aircraft industry is becoming less and less dependent on DoD. Consequently, concepts of civil-military integration will be critical to the ability of a predominantly commercial industry to serve the specialized needs of defense.

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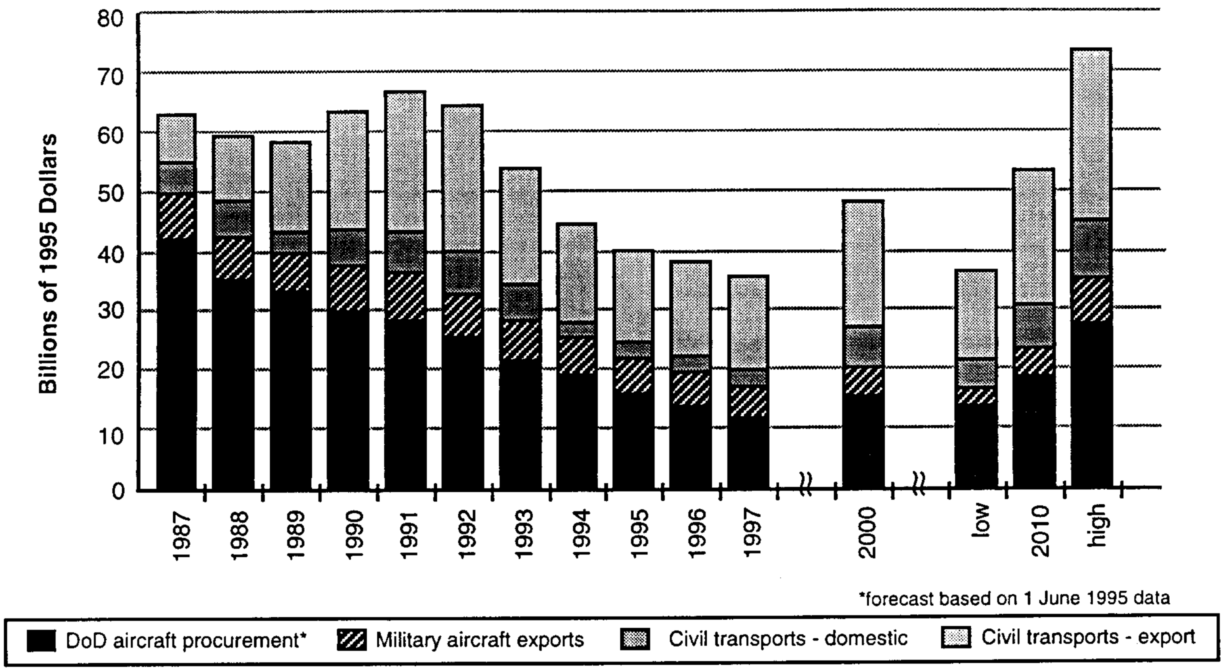
Trends in Aircraft Industry Sales



Source: AIA, Boeing, McDonnell Douglas

TASC

The future health of the overall aircraft industry is of overriding importance in maintaining an ability to restart the B-2 or produce the next-generation bomber. A healthy aircraft industry is needed to keep important suppliers in business and maintain the degree of engineering know-how and innovation necessary for advanced military systems.

The aircraft industry is near the bottom of a long downward trend and the sales mix of many companies is changing. As noted earlier, DoD aircraft procurement in 1997 will be down approximately 70 percent from the 1987 peak, while civil transport sales are projected to recover strongly from their 1997 low, up by as much as 40 percent by the year 2000 and up even more over the following decade. The export portion of aircraft sales has doubled from 25 percent in the mid-1980s to more than 50 percent today.

Data for the year 2000 are from DoD program documents and from forecasts by the major commercial aircraft companies and the leading industry association. A 15 year forecast is necessarily more speculative; therefore, we present low (worst case), most probable, and high estimates in all categories. Again, the data are from authoritative sources, with a large margin for error built in to the range of estimates for the year 2010. Most notably, even the forecast low for 2010 is greater than the forecast for 1997.

Despite current declining sales, the financial health of the aircraft industrial base remains relatively strong. Through acquisitions and restructuring, many companies have actually strengthened their overall financial position and aircraft-related capabilities during this lull in activity. Ongoing consolidation within the aircraft base, which is creating a smaller, leaner, financially sound industry, is discussed in more detail later in this report.

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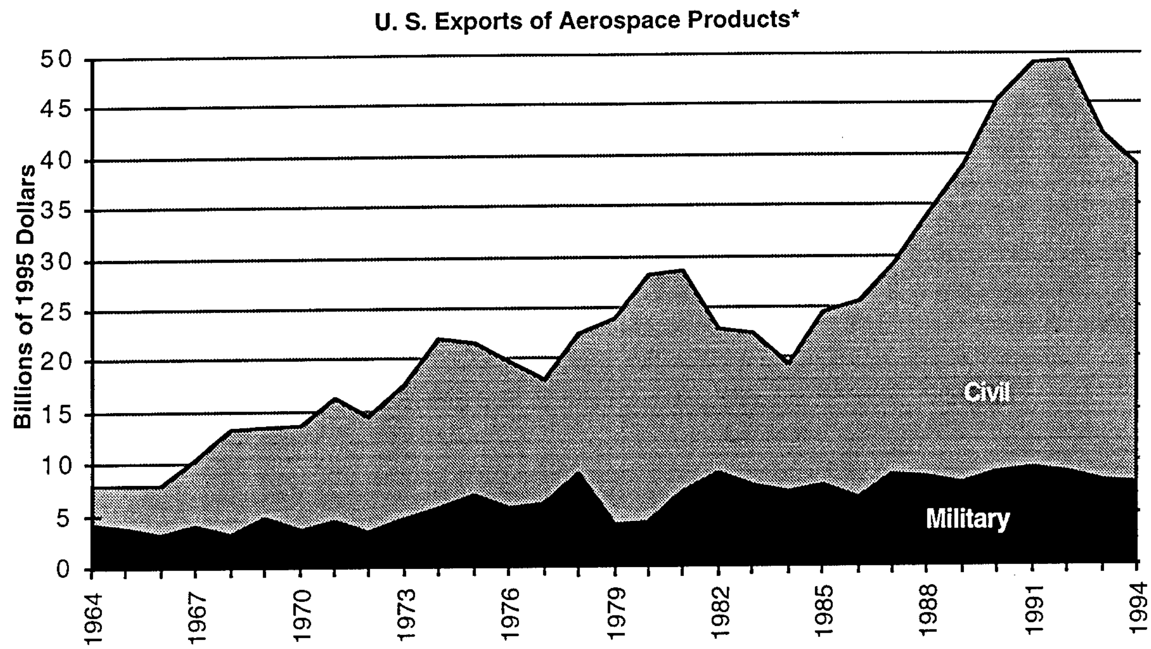
Export Sales -- A Key to Industry Growth



*Primarily aircraft, engines & parts; missiles and parts constitute less than 5% of total

TASC

The export share of the market is becoming increasingly important to the future of domestic aircraft producers; civil and military export sales have increased from 20 percent of the market in the mid-1980s to 50 percent today.

Military exports may play a particularly important role in maintaining military aircraft capabilities as U.S. defense procurement declines. Traditionally, military export sales have constituted over 10 percent of U.S. military aircraft production, but the market is highly competitive and declining military budgets in Europe and the former Soviet Union have led to increased market pressures. Aggressive action will be necessary if domestic producers are to capture a larger share of the global market.

Civil transport sales have been growing since the 1980s, and could reach $1 trillion over the next decade -- a level that is about $50 billion a year over current production. But in this area, too, some uncertainty exists: demand for commercial transports has traditionally fluctuated even more than DoD procurement. To illustrate that volatility, healthy projections belie the fact that 1995 sales are forecast to be 43 percent below 1992 peak levels. Consequently, opportunities created by foreign sales growth must be tempered by the volatility of the market as well as increased competition from foreign producers. Although the U.S. has long dominated the worldwide aerospace market, companies like Airbus Industries have publicly stated their goal of increasing their own share of the civil transport market from their current one third to over half.

The importance to U.S. companies of achieving forecast military export and civil transport sales growth is clear. As one industry analyst put it, loss of market share in these areas could have a larger negative financial impact than cutbacks in DoD aircraft procurement. Actions to strengthen export potential, especially in the area of civil transports, could be far more important to future military aircraft production capabilities (including bombers) than current government funding of bomber R&D and manufacturing.

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"Primes" Produce Diverse Aircraft

- **In the past 45 years, bomber production has shifted from prime to prime:**
  - No firm or team has produced heavy bombers for more than 15 years running
  - No firm or team has won consecutive heavy bomber production contract awards
  - No bomber contract has been awarded to a firm with another fighter, bomber, or military transport in production
- **No heavy bombers were produced between 1962 and 1982 (excluding prototypes). No capabilities were lost during the gap**
- **Over the last 30 years**
  - General Dynamics changed from bomber to fighter
  - Northrop shifted from fighter to bomber, and
  - Lockheed has produced both fighters and transports

TASC

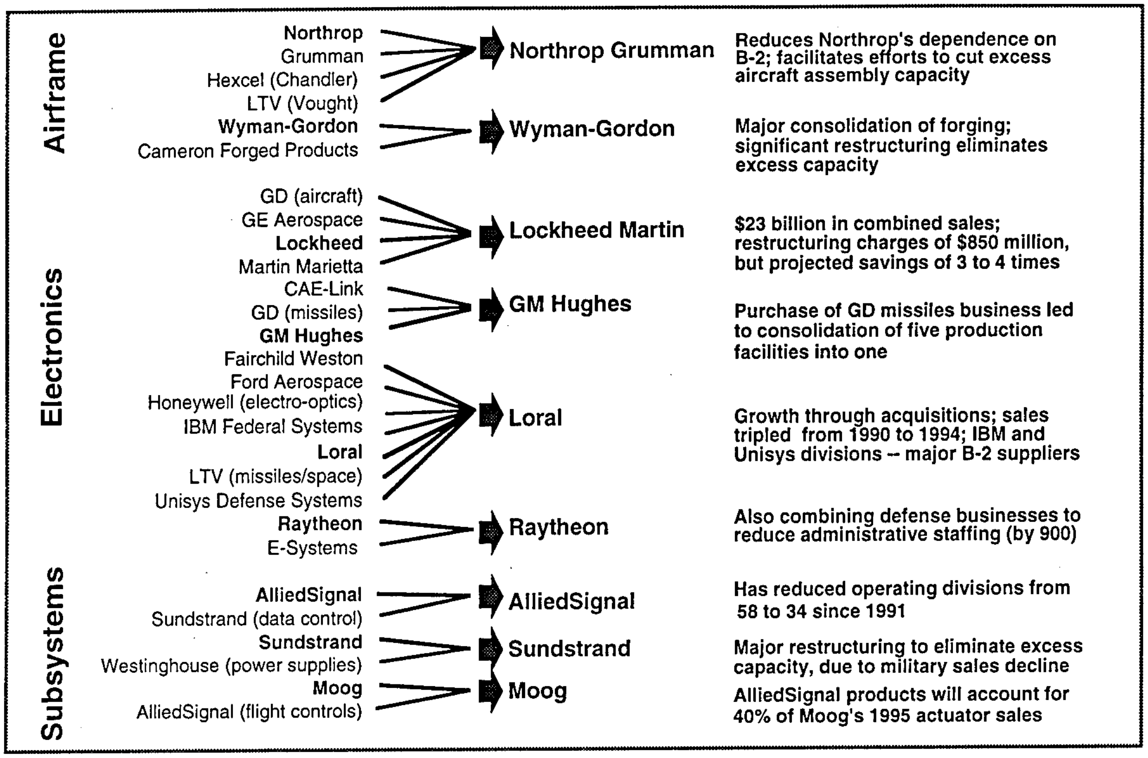
The importance of taking an "aircraft industry" rather than "bomber industry" perspective in this analysis is illustrated by prime contract awards for new bomber aircraft. Traditionally, the aircraft industry has not been rigidly segmented into bomber, fighter, and transport producers. Given the size, dollar value, duration, and infrequency of major contracts, aircraft primes seek to become involved in a mix of new aircraft programs -- as primes or as members of a team. As history has shown, companies produce more than one type of aircraft. The flexibility demonstrated by aircraft primes in the past may be even more pronounced as the industry consolidates and the experience base of the new companies expands.

The aircraft portion of the aerospace industry now consists of four companies having sufficient management, engineering, and manufacturing capabilities to lead a new bomber production team: Boeing; Lockheed Martin; McDonnell Douglas; and Northrop Grumman. All four are large, with Northrop Grumman being the smallest with 1994 sales of over $6 billion. Additionally, Rockwell remains viable as a potential team leader. These companies form different teams for different programs, and would do so for any future bomber program. For example, Boeing is a subcontractor to Northrop Grumman on the B-2 and to Lockheed Martin on F-22, while Northrop Grumman and Lockheed Martin both are suppliers to Boeing for several commercial airplanes.

Increasingly, there is another major reason for companies to form teams to approach new military aircraft programs: these programs have simply become too costly, too complex and too risky for a single company to undertake alone. Even the titans being created in the recent and ongoing wave of mergers and acquisitions would be severely tested by the demands of such programs as the B-2. Although it is not clear which would prime a B-2 restart or next-generation bomber program, there is no reason to doubt that the nation will continue to possess the prime contractor capability to manage it.

Consolidation -- Positioning for the Future

Recent Examples Involving B-2 Contractors



The aircraft industry has undergone periodic consolidations since World War II, each time aircraft demand has declined. At the prime contractor level, the decline in the number of active producers has tracked with the reduction in military aircraft programs and number. For example, there were 13 U.S. military aircraft companies in 1960, when over 1,300 aircraft were produced. Including the recent spate of consolidations, the number of U.S. companies currently building military aircraft is down to four. As the number of prime contractors has declined, so has the number of aircraft subsystems and parts suppliers.

Recent acquisitions by B-2 program participants are indicative of changes within the industry:

- Northrop has reduced its dependence on the B-2 program and strengthened its position as an aircraft producer by acquiring both Grumman and Vought
- The merger of Lockheed and Martin Marietta, along with Lockheed's prior acquisition of General Dynamics' military aircraft business and Martin's acquisition of GE Aerospace, has resulted in a defense/aerospace company that rivals Boeing in annual sales
- The GM Hughes acquisition of GD's missile business strengthened the GM Hughes position in the missile market and resulted in consolidation of missile production facilities
- Loral sales have more than tripled since 1990 through acquisition of five major defense electronics businesses and will continue to grow in 1995 with the acquisition of Unisys Defense Systems.

Consolidations have also had a particularly strong impact on defense electronics firms, major aircraft parts suppliers, and materials suppliers. These actions will reduce the number of companies that will be available to support the B-2 or a new bomber in the future, but they will promote the affordability, diversity, efficiency, corporate backing, and viability of those that remain. Additional examples of consolidation affecting B-2 contractors are shown on the chart. By and large, acquisitions and restructuring activities within the aircraft industrial base have helped speed the process of reducing excess capacity and have enabled many companies to strengthen core businesses despite declining demand.

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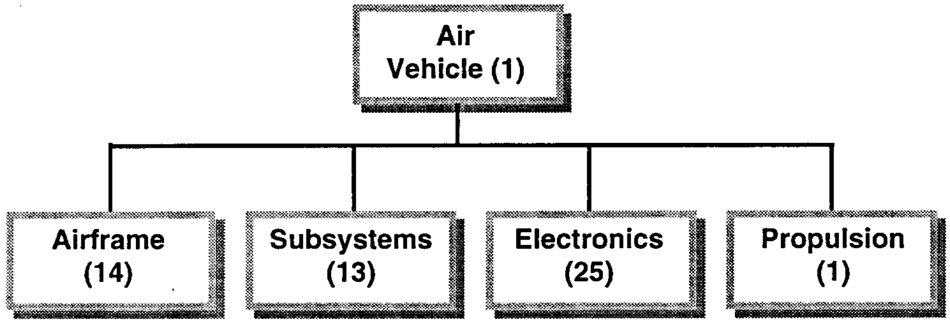
B-2 Suppliers Are *Aircraft* Suppliers



( ) = Number of suppliers identified by Northrop Grumman(NG) as providing more than 0.1% of the value of the aircraft (or 0.01% for electronics) Company names proprietary to NG.

All 54 key B-2 suppliers also supply other aircraft and/or non-aircraft programs.

* Note: The identity of these suppliers is considered Northrop Grumman proprietary

TASC

Flexibility in supplying different aircraft programs is also demonstrated by aerospace industry suppliers. Prime contractors are supported by a broad array of aerospace and non-aerospace firms for aircraft development and production. This supplier base supports not only the aircraft primes, but may also serve the comparatively small helicopter, business aircraft, and light aircraft markets.

At its peak, the B-2 program involved nearly 4,000 suppliers, most of which cannot be considered critical or unique. Northrop Grumman's list of leading B-2 suppliers, which is used for preservation planning and other purposes, includes the 54 companies that account for the largest share of the B-2 cost. All of these suppliers work for other aircraft (and even non-aircraft) programs and will continue to work in their current lines of business after B-2 production ends. Through its own analysis and discussions with industry managers, the study team could identify no key sources that would be lost or otherwise endangered by the end of the B-2 program.

Although the study schedule did not permit the team to separately analyze the viability of the thousands of suppliers that supported the B-2 during its peak years, executives from Northrop Grumman and its major subcontractors (Boeing, Vought, Hughes, and Loral) identified only a single instance (a small dedicated materials supplier) where a supplier was put out of business or left aerospace production when its B-2 orders ended. It appears in this case that the capability can be regenerated, if necessary. Once again, our conclusion is that key capabilities will not be permanently lost when the B-2 program ends.

However, we would again stress the critical role to be played by 1) other military aircraft efforts, such as the F-22 and JAST, in sustaining the technology and industrial capabilities required for high performance military aircraft, and 2) the commercial aircraft industry in sustaining a healthy supplier base.

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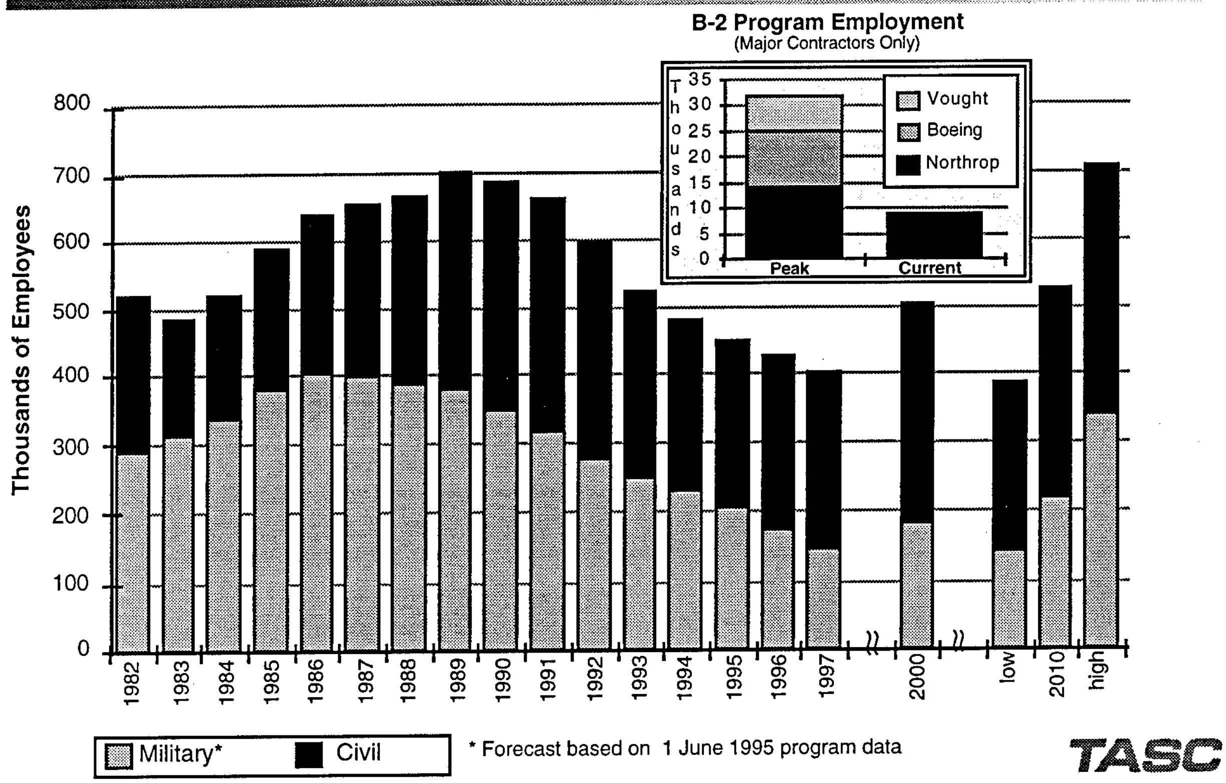
Workforce (Aircraft Industry Only)



* Forecast based on 1 June 1995 program data

TASC

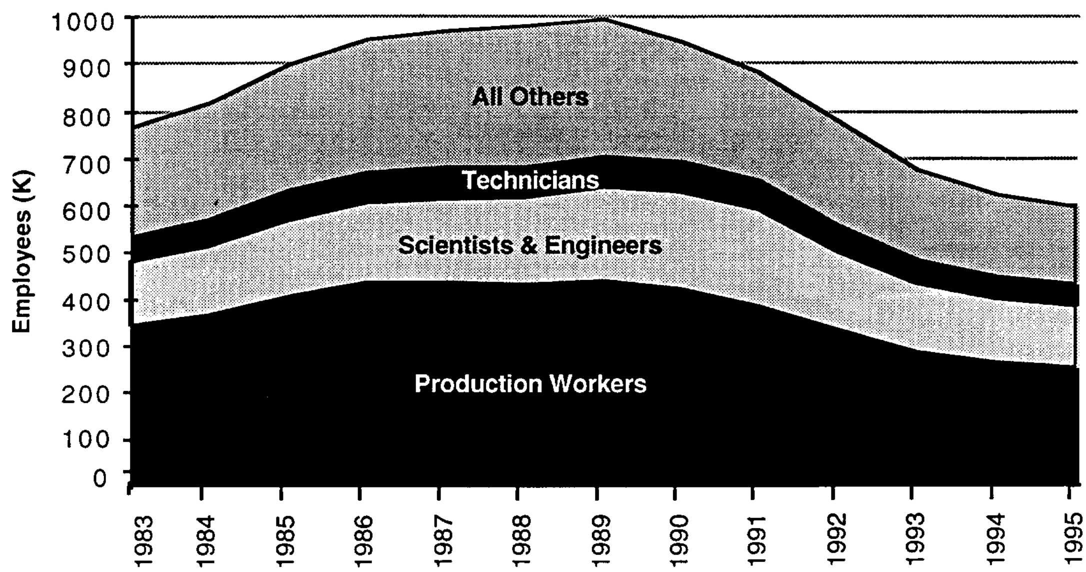
The aircraft industry has been restructuring in response to a changing demand mix, declining sales, and the excessive cost of overcapacity. Aircraft industry employment has been cut by one third over the past six years and additional cuts will occur as sales continue to decline. When jobs bottom out in 1997, employment will have been in decline for eight straight years. (The 75 percent decline in the dedicated B-2 workforce (i.e., that of the three principal airframe structure fabricators shown in the inset), is considerably more dramatic than the industry trend.)

Human resources are generally thought to be the aircraft industry's most important asset, so the protracted decline in employment -- especially with a reversal expected after 1997 -- is reason for some concern. The workforce has traditionally been relatively stable, moving from job to job following major aircraft programs. However, there is anecdotal evidence that industry-wide downturns have changed this pattern. Workers may be taking jobs in other industries or moving from aerospace employment areas, and new workers may view aerospace as a less desirable and stable career than was the case in the past. Whatever the reason, companies recruiting in the late 1990s may find that experienced aerospace workers are hard to come by.

Another trend to watch is a by-product of the shrinking number and size of military aircraft programs. This shrinkage limits the breadth of experience available to new industry employees. A final trend is the declining importance of military aircraft funding in the overall industry sales mix; such funding supports a disproportionate share of R&D (and essential scientists and engineers). Whatever its size, the future aerospace workforce may be somewhat less broadly experienced and less technically sophisticated as a result of these trends.

A positive factor in the employment picture is productivity growth within some segments of the aircraft industry workforce. Although the gains shown for U.S. industry are still relatively modest, foreign manufacturers are showing dramatic productivity increases in their state-of-the-art facilities. Advanced manufacturing methods must be adopted by domestic producers if they are to compete effectively in the international market.

Employment by Occupation (All Aerospace)



*Includes aerospace companies in SICs 372, 376, 366, 381, & 382 only

TASC

Total aerospace industry employment has seen a decline that parallels that of the aircraft industry (prior page). After peaking in 1989, aerospace employment had declined by over a third in only six years. The industry also experienced a slight shift in the employment mix over that period. The production worker portion fell from about 45 percent of the total in 1990 to 42 percent today. In contrast, the number of scientists and engineers currently stands at 22 percent of the workforce, up from its 18 percent share during the mid-1980s. The relative stability of scientists and engineers can be attributed to a variety of factors, including the slow decline in DoD R&D budgets compared to procurement and the reluctance of aerospace employers to lay off "high value" personnel who are viewed as instrumental to future growth.

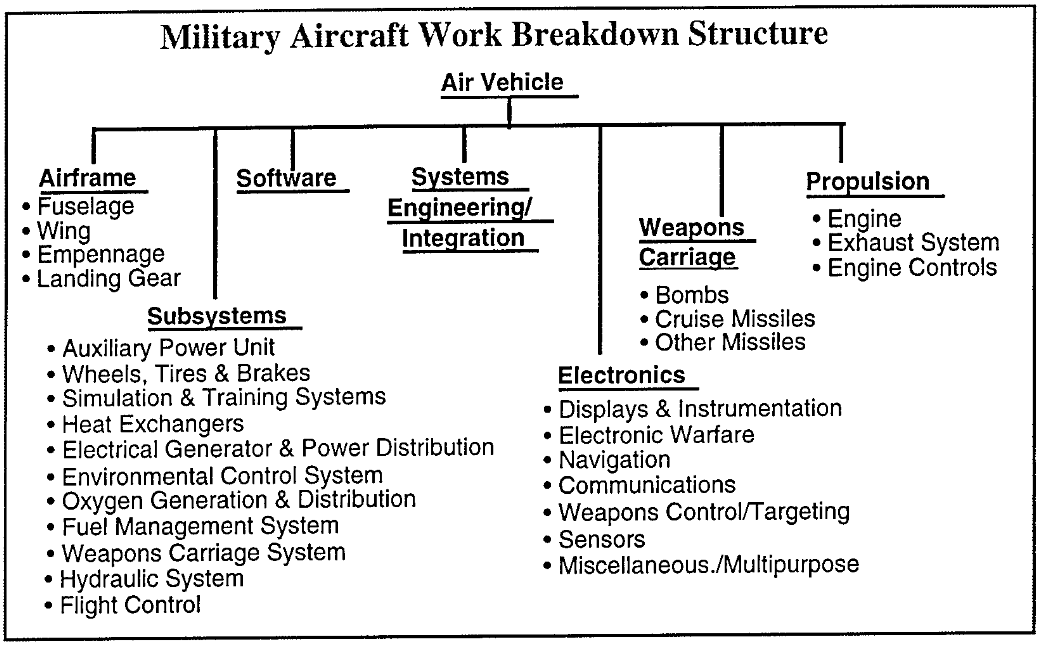
Nevertheless, the aggregate statistics on the pool of scientists and engineers do not reflect the real-world concerns of industry executives as sales decline and the workforce shrinks. A particular concern is the potential loss of individuals who are experienced in managing and integrating large and complex systems. With fewer new programs, new aerospace personnel may be unable to get the breadth of experience that will be required to integrate complex systems in the future..

Core Industrial Capabilities

- The "Bomber Industry"
- Special Features of the B-2

This task has involved identifying core industrial capabilities required by the B-2 and determining whether those capabilities will be available in the future. This subsection builds on the analysis of the aircraft industry and focuses directly on those capabilities specifically required by the B-2 and similar bomber aircraft. The analysis is based heavily on interviews with contractors and government organizations on essential and unique attributes of this type of aircraft.

Identifying Unique B-2 Capabilities



The consensus of about 200 executives representing fifteen organizations: The capabilities required to produce the B-2 are common to other military aircraft.

The observations about the nature of the "bomber industry," the proven willingness and ability of prime contractors to shift between bomber and other aircraft programs, and the flexibility of aircraft industry (and B-2) suppliers provided an important framework for the team's analysis. However, it is also necessary to examine B-2 components in depth to identify any "unique" characteristics that cannot be found elsewhere. The B-2 is an extremely complex and technologically advanced aircraft, and the task of producing such an aircraft should not be understated.

Members of TASC's study team are experienced in various aspects of military aircraft programs, and include several with extensive experience in aircraft industrial analyses. Based on their own experience and information gleaned from a comprehensive literature review, the team prepared and applied a "generic" military aircraft WBS as a central mechanism for data collection and analysis. At all contractor locations, discussions were centered around elements of the WBS as a means to identify any unique industrial capabilities for B-2.

Discussions were structured by means of a series of hypotheses, covering all critical WBS elements. The hypotheses were posed as items for discussion, not preconceived notions that were expected to be "rubber-stamped" by the audience. Particular attention was given to ways in which the "B-2 solution" differed from other aircraft, the impact of these differences, and underlying capabilities and sources.

Like the WBS, the hypotheses (ten, altogether) were formulated out of the collective experience base of the TASC team; that is, the team considered them to be potentially valid statements, but ones to be tested in group discussions. TASC anticipated that some of the hypotheses would be controversial. Quite the contrary: the hypotheses generated virtually no emotional responses but did stimulate lively, reasonable, and highly informed discussions in every group meeting. Briefly summarized -- there were different opinions about the "degree" of validity of some of the hypotheses, but a remarkable consensus that they were valid statements.

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Sample Hypotheses -- Airframes

Stealth (if required)	**Underlying technologies, materials, and processes are independent of specific applications.** ***Continued R&D, operation of F-117 and B-2, and development and operation of other stealth systems (e.g., F-22, JAST) will maintain capabilities for future bomber***
Large composite components (if required)	**Underlying technologies, materials, and processes are independent of specific applications and will be maintained.** Even if composites are not used in future commercial aircraft wings, ***scale-up from smaller composites structures use on other military and commercial aircraft will satisfy future requirements***
Honeycomb (if required)	**Underlying technologies, materials and processes are independent of specific applications. However, high-performance honeycomb in sizes required by bombers is rarely needed by other aircraft.** ***The total volume used by the domestic aircraft industry may be insufficient to retain a domestic supplier***
Other airframe	**Needed by other combat, special purpose & commercial aircraft.** ***Continued operation and production of these aircraft will sustain capabilities for bombers***

PROPOSITION

Generic bomber requirements are not unique (except for honeycomb, if required by specific point designs). Technology advances and industrial base capabilities will be sustained by the requirements of other aircraft.

An example of the hypotheses employed by the study team is shown above. The example, representing a generic heavy bomber airframe, is somewhat controversial for the B-2, since the B-2's airframe requires considerable time and touch labor to achieve the necessary level of "stealthiness."

Hypotheses were developed for all major WBS elements shown in the previous chart, and discussions were frequently directed to components at WBS level 5 and below.

The data collected during the visits were compiled by the study team, which established a profile of different "degrees of uniqueness" among WBS elements. The team's compilation of the results of the analysis was compared with extant documentation (see Appendix B) and, in a few cases, subjected to extended analysis by subject experts.

In nearly all WBS areas, **no distinct industrial capabilities applicable only to the B-2 could be identified**. Industry either produced analogous components for other customers, or the capabilities to produce the component existed independently of the B-2 program. However, in a few important areas, there was less certainty about the extent to which B-2 requirements could be supported by available industrial capabilities, with some believing that underlying capabilities used in other programs could be adapted to satisfy B-2 requirements while others were doubtful. Some of the areas in which B-2 differences are notable are described in the following pages.

There is a fine line that must be drawn here. It is technically correct to say that the B-2 requires no unique industrial capabilities; that is, all of the specified capabilities used to produce this complex aircraft were developed from generic capabilities already available in the industrial base. The same statement is true of every specific point design: specific tooling and processes used to produce every aircraft are unique, but were derived from generic capabilities in the industrial base. Obviously there has been a continuing flow of new technologies into the military aircraft market and these new technologies have required new production processes and other capabilities to enable them to be incorporated into production aircraft. Even so, existing capabilities tend to be the building blocks for further advances.

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Hypotheses: Bomber Air Vehicle

WBS Element	Unique Capabilities	Required Capabilities
Structure (fuselage, wing, empennage, landing gear)	None known (possibly honeycomb)	Satisfied by Aircraft Industrial Base
Propulsion (engine, exhaust system, engine controls)	None known	Satisfied by Aircraft Industrial Base
Electronics (displays & instrumentation, EW, navigation, sensors, communications, weapons control/ targeting, misc.)	None known (possibly radiation hardening)	Satisfied by Aircraft Industrial Base
Weapons (bombs, cruise missiles, other missiles)	None known	Satisfied by Aircraft Industrial Base
Subsystems (e.g., APU, fuel mgmt, wheels, tires & brakes, sim. & trng systems, heat exchangers, elect. generation & dist., envir. control system)	Extensive internal weapons carriage	Satisfied by Aircraft Industrial Base
Software	None known	Satisfied by Aircraft Industrial Base
Program/Systems Engineering/Integration	None known	Satisfied by Aircraft Industrial Base

Note: The above hypotheses were tested by the project team, and generally validated, during discussions with industry and AF representatives.

TASC

The matrix above summarizes the hypotheses and their implications: very few capabilities are even potentially unique and all requirements can be satisfied by the broader industrial base. We expected these statements to be controversial and used them to stimulate discussion. But as noted earlier, there was little real disagreement and the perception remains that most capabilities to support a heavy bomber are shared in some form by other aircraft, and can be satisfied by elements of the aerospace base that are sustained by other military and commercial programs.

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Special Features of B-2

Specific Features of B-2

Air Vehicle
- Complexity
- Systems Integration

Airframe
- Large composites
- Large titanium forgings, castings, extrusions & superplastic formed parts
- Tight tolerances on large composites & titanium
- Integrated wing design with VLO shaping
- LO materials
- Outer moldline tolerances
  - Dimensions
  - Smoothness
- Edge structures
- Treated honeycomb
- LO/hardened windshield

Subsystems
- Flight control integration
- Fuel management
- Rapid actuators
- Weapons integration
- Hydraulics
- Embedded air data system

Software
- Code
- Integration

Propulsion
- Engine fan
- Exhaust system

Electronics
- Avionics integration
- Embedded antennas
- LPI radar/radome integration
- Waveguides
- Defense management system

When first developed, many features required development as unique capabilities, but these capabilities are now available generally in the industry.

TASC

While most B-2 capabilities were found to be active within the aircraft industry, the "uniqueness" of a few of the B-2's features warrants special attention. Undeniably, the B-2 is a complex aircraft that is unlike any other. Industrial capabilities have developed and produced a truly unique airplane -- not just in the sense that every airplane is unique, but also in its combination of bomber mission capabilities, configuration, and stealthiness. The companies responsible for the B-2 have employed many special materials and innovative processes to ensure that the aircraft meets its mission requirements. Some of the important features that differentiate the B-2 from other aircraft are shown on this chart.

As previously stated, the B-2's demanding performance requirements have dictated very specific (and challenging) design solutions. The B-2 team's achievements were precedent-setting in major respects, but from an industrial viewpoint, it is important to note that the basic industrial capabilities to produce the B-2 were, by definition, present in some form in the aircraft industry at the start of B-2 production a decade ago. Although many of these "revolutionary" features may not have been supported by a mature base of industrial capabilities when they were new, technologies that were first applied to B-2 have since found use in other programs, thereby expanding capabilities to a wider network of sources.

The next six charts address four major WBS elements, including those that have posed particular challenges for the B-2:

- The air vehicle (**system integration**)
- Airframe (**stealth, structures**, and **large composites**)
- **Subsystems**
- **Electronics**.

Three of the charts address aspects of the airframe, which clearly is the heart of the bomber's advanced technology capabilities.

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System Integration

- **Experienced, skilled engineering managers are needed to formulate programs.**
- B-2 Managers:

Business	Technical
Selected and managed 4,000 suppliers nationwide	Blended wing/body aerodynamics with low observable large composite airframe structure
Established major suppliers' paperless operations	Developed 132 on-board computers; 1.8 million lines of code

- **Traditionally, skilled systems engineers have migrated from existing to new programs**
  - B-2 program used shuttle, B-1, and others as sources of skilled managers
- **In 1990s there will be fewer military aircraft programs to develop these skills (B-2, F-22, V-22, F-18 and C-17)**
- **Software development and integration is a major and continuously growing problem across the military aircraft industry**

TASC

Experience and skills in systems management and integration are fundamental to the success of any large aircraft program. However, the "revolutionary" nature of the B-2 (coupled with its shroud of secrecy) caused its transition from development to production to be among the most difficult faced by any weapon system. The management team -- business as well as technical -- that ultimately succeeded was one that had substantial depth of experience in the management of large, complex systems. When the early B-2 program faced extreme problems, new team members were drawn from other large aerospace programs, including the space shuttle and the B-1 bomber. This team is widely given credit for the success of the B-2 program.

The elements shown above are illustrative of the management requirements associated with the B-2, but by no means do they convey their magnitude. The integration of a highly complex program demands both specialized skills and hands-on experience, and there is concern within the industry that the number of new program starts is declining so sharply that the opportunity for gaining experience -- especially on multiple programs -- may erode. This problem could be exacerbated by the replacement of experienced but aging workers by a new generation of inexperienced personnel.

Although this issue has been important to the B-2 and will have a major impact on any future bomber program, its impact is aerospace-wide and only negligibly affected by the decision to limit the B-2 program to 21 aircraft. **The continuation of B-2 production would not exercise these skills as did the original development and transition to production.** Currently, within the defense budget there are a number of ongoing programs that, if maintained at their projected levels, would be sufficiently complex to maintain the requisite system integration skills needed for a bomber restart and, more importantly, for development of a new bomber program.

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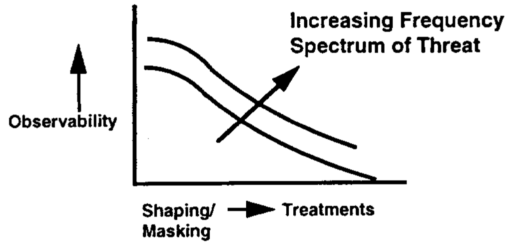
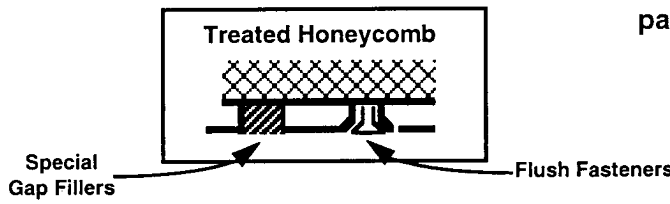
Stealth



- Shaping and masking are key to all stealthy aircraft
- Treatment solutions for large and small aircraft are similar
- Different materials perform the same functions
- All military aircraft producers have participated in stealth programs



Stealth capabilities for future bombers will be retained and advanced through B-2 Program Depot Maintenance, F-22, JAST RDT&E and production, and other programs

TASC

Stealth requirements are the source of the most demanding of the B-2's special features. Stealth has its strongest effect on airframe WBS elements, including a unique integrated wing design with very low observables (VLO) shaping, extensive use of low observables (LO) materials, and unprecedented outer moldline tolerances. These features have presented manufacturing challenges to B-2 contractors. Beyond the airframe, stealth considerations led to the requirement to mask inlet and exhaust systems, as well as to cool the exhaust, which required a unique and extremely complex exhaust system. Such innovative design features in turn dictated a unique engine fan design. Despite the fact that the B-2's electronics systems are generally similar to those of other aircraft, stealth-driven requirements for embedded antennas and for integration of the low probability of intercept (LPI) radar and its radome led to unique B-2 design solutions.

Stealth technologies required for the production of the B-2 are similar to those being used on the F-22. Most stealth capabilities are achieved through design operations which shape the vehicle to reduce/eliminate the return of energy to the radiating source and mask the major sources of return and vehicle radiation, such as the engine and canopy, by burying them within the airframe, and by local treatments. The achievement of these stealth characteristics is a basic tenet of LO design, a capability which now resides in important segments of the industry and would be available for either a new bomber or a B-2 restart.

Stealth materials are employed to absorb energy in selected areas, and to collect and control energy in other areas of the structure. Non-metallic cores are used in some portions of stealth systems and are treated to absorb particular energy inputs. One particularly important material is honeycomb. Northrop Grumman acquired a supplier of this material to ensure a secure source for the B-2. However, honeycomb is also used on other vehicles and is available from other sources, including DoD and commercial suppliers.

In summary, **stealth features associated with the B-2 would be available to support the restart of B-2 production or the development of a new large bomber.** Companies currently involved in the development of LO systems could reconstitute their capability to support either option in a reasonable time frame. Continued R&D in the area by both DoD and industry raises the additional possibility that improved LO materials and manufacturing methods could be available for these systems, improving both effectiveness and cost.

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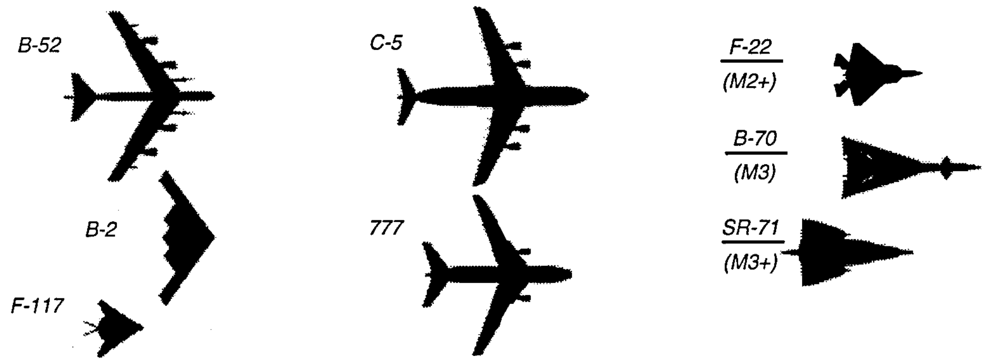
Structures

Subsonic Combat* | **Subsonic Non-Combat*** | **Supersonic***



- **Analytic methods and tools (e.g., finite element analysis, etc.), materials, and processes for aircraft structures are common across industry**
- **Specific configurations are driven by design solutions of particular mission and aerodynamic requirements**
- **Structures for high performance military aircraft are more complex than for commercial aircraft. Internal weapons carriage causes special structural problems for stealth aircraft**

Structural arrangement are similar for different types of military aircraft (including flying wing) and require no unique industrial base capabilities

*Figures not to scale

TASC

The basic design and analysis tools, materials and processes for aircraft structures are common across the industry. The major departures from industry norms for structure fabrication and assembly for the B-2 were caused by stealth requirements. Assembly for any stealth aircraft is an extremely exacting and time consuming process, but the issues are the same for both bomber and attack/fighter systems. For the B-2, these requirements created a number of manufacturing challenges:

- Designed and built from the outside-in, to outer moldline tolerances for unprecedented shaping and smoothness control
- Very large composite airframe structures -- including specially dipped honeycomb core
- Special shaping and coatings for leading edges
- Smooth, flush and non-wavy external surfaces for low-observability, special taping, caulking, and smoothing operations
- An order-of-magnitude greater precision for structural tolerances compared to commercial aircraft
- Adaptive drilling to sense the changes in materials (composites-titanium) when drilling through layers of the structure for fastener holes
- Three weeks to mate major sections during assembly using theodolite alignment (versus eight hours for the B-1)
- Embedded antennas
- Specially designed LO tail pipes
- Precise control of paint thickness.

Thus, while it is true that no unique industrial capabilities are required, it also is true that the B-2 program advanced the state-of-the-art in many processes. This capability will not disappear as long as current military aircraft plans are implemented as scheduled.

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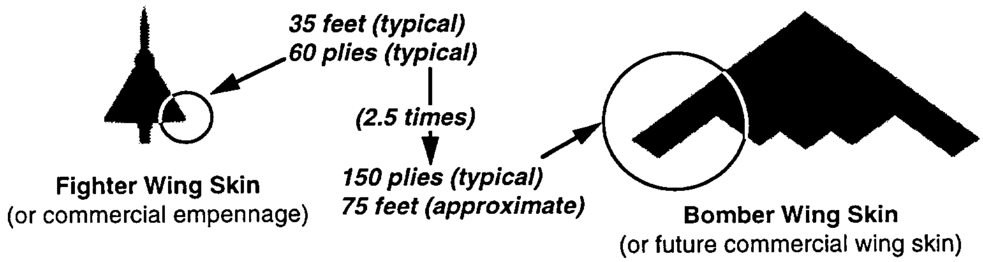
Composite Structures



- **B-2 composite structures are the largest ever in a production program**
  - scale-up was difficult and expensive
  - significant geometry and repeatability problems
- **Materials should be available through support from programs like F-22, V-22, and Comanche**

Restarting manufacture of composite structures of comparable size (e.g., commercial wing structures) will require relearning to address scale-up problems.

TASC

Composite materials provide the performance and manufacturing flexibility necessary to achieve the highly efficient structures and surface-controlled shaping required for stealth. The B-2 contains the largest airframe composite structures ever produced. Its wing box is about 2.5 times the size of fighter wings or commercial aircraft empennages in both planform and thickness. Despite their size, large composite structures for the B-2 were fabricated using conventional materials processing (tape laying, hand lay-up, and autoclave curing) and subsequent inspection (x-ray and through-transmission ultrasonics). These techniques are in daily use throughout the aircraft industry. However, straightforward scale-up from the sizes and dimensional tolerances typical of fighter and commercial aircraft structures to those required for the B-2 was complicated by the need to create and install larger-scale equipment, to use graphite lay-up tools to reduce mass, and to empirically solve problems caused by incomplete understanding of non-linear scale effects in de-bulking and curing.

In the absence of B-2 production, industry-wide composites fabrication capabilities for fighter-scale components will be retained through ongoing commercial and military aircraft production (e.g., 757, 767, 777, MD-80, AV-8B, F/A-18, F-15, F-22). Developmental efforts by McDonnell Douglas and Boeing may lead to commercial aircraft composite wings in production within ten years. If so, industrial base capabilities for heavy bombers would be available, probably with improved affordability. If not, scale-up efforts to reconstitute specific capabilities for the B-2 or a new heavy bomber will be required, similar to those originally required for the B-2.

In addition to the B-2 and other production applications, composites will continue to be advanced in development programs such as the F-22, F/A-18E/F, V-22 and JAST, which are developing composite technologies for fighter-class vehicles. Also, the National Aeronautics and Space Administration (NASA) and the Advanced Research Projects Agency (ARPA) are addressing the expanded use of composites in primary structures of engines and airframes for large aircraft. These programs provide the necessary technologies to support either the restart of B-2 production or the development of a new heavy bomber. **Overall there are no unique technologies involved with composites and their manufacture for the B-2 that are not available from the aircraft industry or that could not be reconstituted within a reasonable time.**

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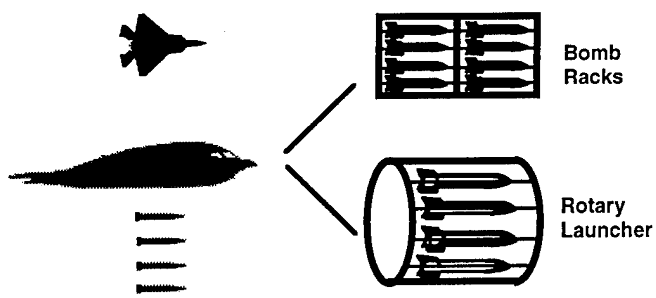
Subsystems



- Auxiliary power unit
- Wheels, tires and brakes
- Simulation and training systems
- Heat exchanger
- Electric generator and distribution
- Environmental control system
- Oxygen generation and distribution
- Fuel management system
- Weapons carriage
- Hydraulic system
- Flight control

- **Rotary launchers and large bomb racks are needed only by heavy bombers, and they are not technically difficult to produce**

An adequate industrial infrastructure will support these various subsystems

TASC

A dozen discrete systems were gathered under the title "Subsystems" in the generic WBS shown earlier in this report. Of these, only one -- the specific type of weapons carriage -- is unique to heavy bombers: rotary launchers and large bomb racks that are used in all operational U.S. bombers -- the B-52, the B-1B, and the B-2. Among these, only the B-2 must carry its weapons internally to maintain stealthiness. With B-2 production complete, there will be no ongoing production of large bomb racks or rotary launchers. However, these are not technically difficult to produce and this capability can be reestablished when required.

Other B-2 subsystems are more technologically challenging to produce than comparable components on other aircraft. Actuators for opening and closing bomb bay doors, for example, are very fast-acting. During periods when the bomb bay doors are open, the aircraft's stealthiness is degraded, so the doors must be opened and closed as rapidly as possible. The actuators are produced to higher performance standards than the slower-acting ones used on other aircraft, but they still are produced by the same suppliers.

Some of the other subsystems are more complex than those on other aircraft. For example, the B-2's fuel management system continuously monitors and adjusts fuel storage to maintain stability of the bomber's center of gravity.

Nevertheless, **most of the subsystems are basically common to other military and commercial aircraft. Supplier companies design or participate in the design of most of them, and also produce them. There is an adequate industrial infrastructure to support future bomber subsystem needs.**

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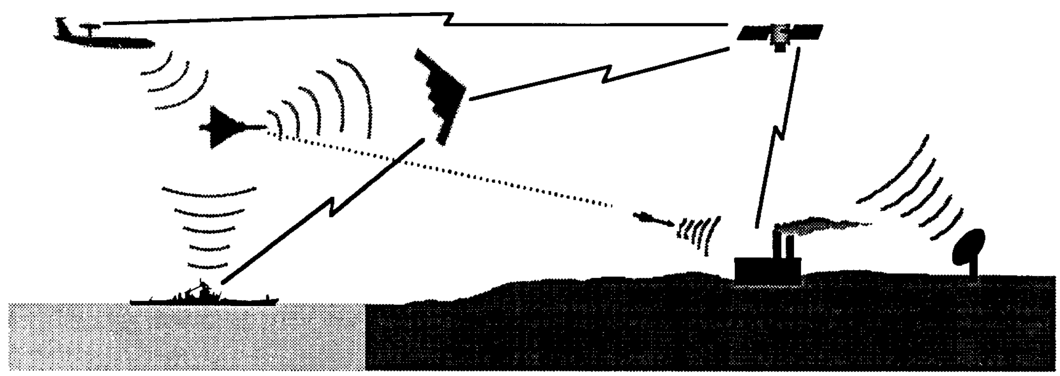
Electronics



- Electronic systems pervade the modern battlefield
- Military electronics technologies cut across all aerospace and defense sectors, as well as some commercial sectors (e.g., communications)
- Electronics subsystems are unique solutions to specific requirements and draw on available technologies

Bomber electronics are a small part of the total electronics industry, and require no unique industry capabilities.

TASC

The B-2's electronics systems are numerous and complex, but they are not fundamentally different from similar systems in other aircraft. The processes required to design and "build-up" to aircraft system level are essentially the same, even though the resulting systems may be very different.

Two of the problems that allegedly pervade military electronics systems are 1) they tend to be "obsolete" by the time they are fielded due to their complexity and unique military specifications and standards and 2) placement of numerous, extremely complex and dense electronics subsystems in a relatively small aircraft platform creates very difficult system engineering and integration problems. The B-2 has experienced both problems, but not to an unusual level, and the continuation or termination of B-2 production will have no impact on how these problems affect other military programs.

Electronics for the B-2 specifically, and bombers in general, are a small part of the defense electronics sector and an even smaller part of the electronics industry. Rapid technology advancement and continuous growth are unquestionable electronics industry trends, but the small size of the military sector relative to other electronics markets may limit the priority and influence of military electronics buyers in the future. This has been a growing issue and will continue to increase in importance -- whether or not DoD continues B-2 production.

Another potential electronics issue is manufacturing and program management/systems engineering. While the lack of new systems in the future may limit the industry's experience base in these disciplines, electronics capabilities are expected to remain robust as modification and upgrade programs continue. Most companies in the industry will also utilize capabilities required by bombers in alternative aerospace and non-aerospace markets.

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Conclusions about B-2

- **The B-2:**
  - Is an extremely complex "point design" solution to the most demanding mission requirements
  - Required precedent-setting solutions to implement unprecedented manufacturing requirements
  - Nevertheless evolved from capabilities already nascent and still growing in the aircraft industrial base
- **Termination of B-2 will cause the loss of specific manufacturing processes/systems, but not loss of basic capabilities**
  - Where capabilities erode, they can be revitalized when required

TASC

Structured interviews with aircraft industry executives and government program managers, engineering analyses of the B-2 and other aircraft, and economic and financial analyses all pointed to the same conclusion: in terms of industrial capabilities, there is nothing about the B-2 that is unique or that cannot be recreated by industry if required.

The discussions and analysis of WBS elements lead directly to the first major conclusion of the study:

> **The capabilities required to produce the B-2 today are common to other military aircraft and will not be lost with the conclusion of the B-2 program. B-2 industrial capabilities are not unique.**

The conclusion unavoidably balances on that thin line between specific design solutions and more generic basic capabilities. The team found that the B-2 has many features that set it apart, to a greater or lesser extent, from other advanced military aircraft, but that the industrial capabilities needed to produce these features can be found in the broad aircraft industry. These capabilities are not unique to the B-2 and will not disappear if the B-2 program concludes.

While the production of a particular component or subsystem might be terminated when B-2 contract activity ends (most have already, in fact), industrial capabilities will still be applied to other aircraft. Similarly, the conclusion of B-2 work will lead to the diversion of facilities and/or reallocation of labor and equipment to other aircraft programs. If a new bomber or B-2 restart is required in the future, essential capabilities would still be available, subject to the assumptions that 1) critical skills and capabilities are maintained and advanced through other military aircraft programs and technology efforts such as the F-22 and JAST and 2) a robust commercial aircraft industry continues to sustain a healthy supplier base. These assumptions are discussed in more detail later in this report.

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Core Industrial Capabilities: Task 1 Findings

- **There is no distinct "bomber industry"**
- **Industrial capabilities required for bombers do not depend on continued B-2 production**
- **B-2 does have specific features that differ from other aircraft in areas such as stealth, structures, electronics, and weapons carriage; however**
  - Some of these features are more widely used on other military aircraft now
- **Capabilities will be maintained and enhanced by other military and commercial aircraft programs**
  - They provide a base to support B-2 restart or new bomber if needed
- **Industry projected out-year growth gives added confidence that needed capabilities will be available**
- **Continued capability in these areas will depend on the continuation of other military programs, particularly F-22 and, later, JAST**

TASC

When one examines the military aircraft WBS below the third level, it is clear that, although B-2 WBS elements may possess numerous specific features that enable the aircraft to meet its mission requirements, the capabilities to create a B-2 are found across companies that support a wide range of aircraft programs, often with very similar products. In short, there is no unique bomber industry.

"Revolutionary" B-2 approaches have been diffused across industry and are now more widely available than when the B-2 program was new. A high-technology industry is always forced to struggle when new, immature technologies are introduced as a means of meeting a new generation of performance goals. When B-2 production began, these technologies required industry to develop new capabilities for manufacturing the new system and its key components. Today, these technologies and their underlying capabilities are more widely used. Commonality among aircraft programs means that "bomber capabilities" will not degrade even with an extended gap in bomber production. Technologies in the areas of stealth, composites, avionics, software generation, and the like will continue to evolve through their application to other aircraft programs such as the F-22, while pressures for improved affordability will improve manufacturing processes and provide impetus for acquisition reform measures. Other, broader capabilities will depend upon the continuation of a healthy, world-class domestic aircraft industry into the future. All of the aircraft industry forecasts examined by the study team conclude that the industry will experience a turnaround beginning in 1998, chiefly fueled by increasing commercial sales. Recent restructuring by major firms in that industry has reduced the overall number of active companies, but it has diminished chronic problems with over-capacity and led to a leaner industry, without any loss of critical capabilities.

Finally, in the absence of a dedicated bomber industry, a future bomber will rely on technologies and capabilities being developed for next-generation application to the F-22 and JAST. Although these fighter aircraft programs may not be directly comparable, advances in stealth, propulsion, and other areas will be adaptable for use in a future bomber.

Restarting the B-2

A decision to cease production of B-2s does not rule out the potential need to produce additional bombers in the future. One way of obtaining them is to: restart the existing B-2 program, with minor modifications. This section reports on the project team's second analysis task, which examined industry's ability to restart B-2 production in the future.

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Restarting the B-2

- **Near-term B-2 continuation far from certain**
  - DoD does not see compelling need
  - Requirements study concluded additional B-2s not cost effective
  - Even with limited "advanced procurement" in FY96, full funding may be infeasible
- **Mid-term restart needs to be considered**
  - "Threat-driven" requirement could emerge
  - Response to attrition and obsolescence of current bomber assets
- **Low-cost restart planning prudent, even for a low-probability event**
  - Other programs offer precedents

TASC

A recent DoD study, performed by the Institute for Defense Analyses, found that the B-2 is less cost-effective in today's high-priority scenarios than B-52s and B-1Bs, fitted with PGMs. The B-2's stealthiness was driven by a different set of mission requirements than are encountered today -- penetrating heavily defended Soviet airspace, undefended, in a potential nuclear environment. That scenario is now seen as unlikely, and DoD believes that the currently planned B-2 force of 20 aircraft is adequate. This view tends to mitigate against the restart of the B-2.

Nevertheless, it is important to consider a possible restart early on if such an option is desired. Effective restart planning is a hedge against an unexpected change in the world politico-military situation. An analysis of restart issues also provides information on capabilities that could hinder the production of additional aircraft if and when they are needed. Further, there are certain minimal planning activities and some very low-cost material conservation actions that provide a prudent level of insurance for a restart at an affordable level of cost. For example, preservation and storage of government-owned tooling against the eventuality of a restart has been commonplace in past programs.

This restart analysis builds heavily on interviews with contractor and government organizations, including Northrop Grumman (NG) at Pico Rivera and Palmdale, CA; Rockwell and Lockheed Martin at Palmdale; Lockheed Martin at Marietta GA; Boeing in Seattle, WA; NG Vought in Grand Prairie, TX; McDonnell Douglas in St. Louis, MO; Hughes in El Segundo, CA; and Loral in Owego, NY.

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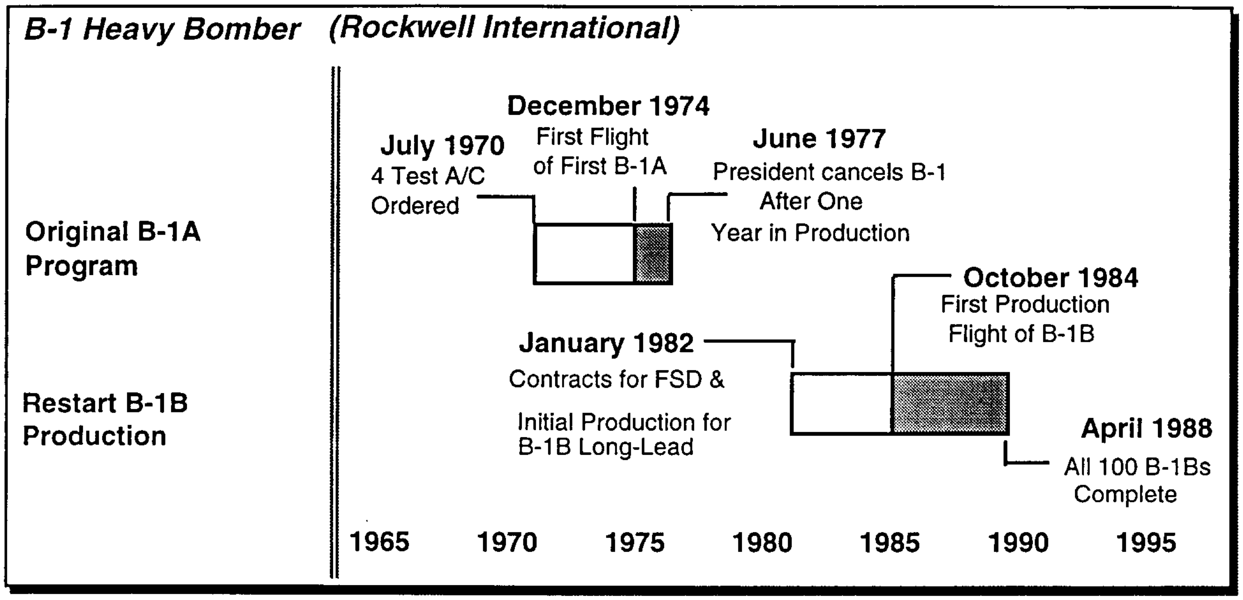
B-1 Restart



TASC

The B-1 bomber is the most relevant analogy to a potential restart of the B-2. The first life of the B-1 was relatively short. The design was frozen in 1971 and the first flight of the first aircraft took place on December 23, 1974. However, on June 30, 1977, President Carter announced that the B-1 program would be canceled, after only a year in production. The program had built up to a maximum level of about 9,000 people, with most work done at El Segundo, CA and at Site 3 at Palmdale, CA. At the completion of the program, three flight test aircraft, one ground test aircraft, and 27 engines had been ordered.

Rockwell, the prime contractor, did not accept the cancellation lightly and vigorously advocated a program restart. In the belief that the program eventually would be restarted, Rockwell continued development, flight test, studies, and Independent Research and Development (IR&D). Key B-1 personnel were lent to other aerospace companies and assigned to other Rockwell work in anticipation of being recalled. Rockwell bet correctly. After a gap of almost seven years, the company received contracts for Full Scale Development (FSD) in January 1982 and initial production for long-lead items for a B-1B. A total of 100 aircraft was later ordered. Twenty thousand people were hired. Extensive planning, equipment procurement, and facilities preparations for manufacturing were also required. Manufacturing took place at El Segundo, at a new, one million square foot facility at Palmdale, and at upgraded facilities at Columbus, OH and at Tulsa, OK. A network of 3,500 suppliers and subcontractors was established, using many from the original B-1 team.

The first production flight of a B-1B was in October 1984, and all deliveries were completed by the end of April 1988, two months ahead of contract schedule.

The B-1 restart experience was molded by Rockwell's extensive efforts to keep its supplier base and labor force ready during the gap in production. The relative ease of restarting the program after a seven year gap suggests that proportional reductions in schedules and costs might also be achievable for a B-2 restart. The potential economies of a restart could be outweighed by the need for major modifications and/or a new design, which become more attractive as time goes by and technology advances.

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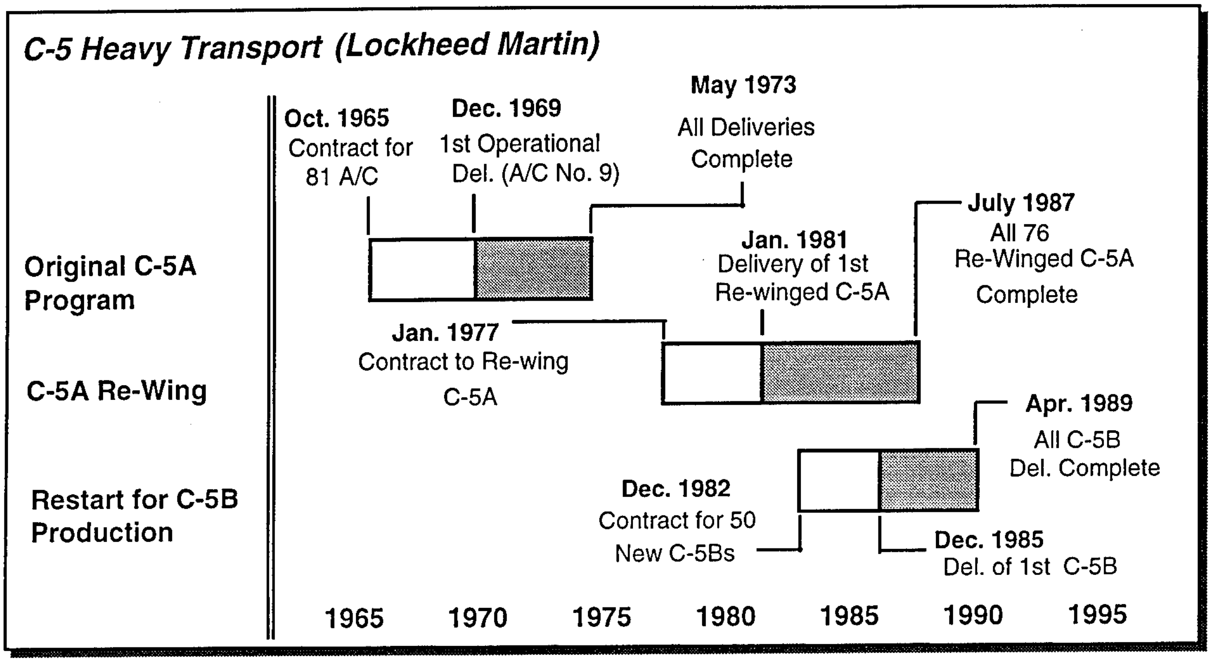
C-5 Restart



The original contract for 81 C-5A aircraft was awarded to Lockheed-Georgia in Marietta, GA in October 1965. The first eight aircraft were used for tests and the first operational delivery (Aircraft no. 9) took place in December 1969. All of the aircraft had been delivered by May 1973. The workforce was reduced from a peak of almost 33,000 in August 1969 to less than 9,000 by September 1977.

In contrast to the uncertainty (at best) that B-2 production will be renewed, restart was an important component of the C-5A program from the completion of initial deliveries..At that time, the Air Force instructed Lockheed to retain all necessary tooling in production readiness to facilitate restart and first deliveries of basic-configuration C-5s in approximately three years. However, no one actually knew if the production would ever start up again. During this period of time, Lockheed manufactured C-130 aircraft and performed a program to stretch the C-141 transport aircraft. The employment level at Marietta was 9,576 near the end of 1978.

Lockheed was awarded a design contract in January 1976, and a contract to re-wing one C-5A in January 1977. Avco Aerostructures of Nashville, TN, was a major subcontractor as the supplier of the wings. The delivery of the first re-winged aircraft was in January 1981. The employment level at Marietta was 13, 286 by the end of that year. The first delivery from the follow-on order was in March 1983. The re-winging of a total of 76 aircraft had been completed by July 1987.

The final contract for the new production of 50 C-5B aircraft was awarded to Lockheed in December 1982. The C-5B contained a number of improvements, including: a simplified automatic flight control system; lighter, more reliable color weather radar; an advanced navigation/communication system; and a digital air data computer. The C-5B had improved engines with increased reliability, and much of the aircraft used new, stronger, and more corrosion-resistant alloys. The first delivery took place on December 28, 1985, and all 50 aircraft had been delivered by April 17, 1989. The employment level at Marietta reached a peak of 20, 238 in October 1987 and was reduced to 10,557 in April 1989 at the end of the C-5B program.

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Restart Checklist

- **Checklist developed by Lockheed to support restart of C-5**
- **Common-sense approach to restarting program**
- **Covers major areas:**
  - Configuration
  - Bill of materials
  - Make or buy items
  - Critical supplier identification
  - Identification of new or alternative suppliers
  - Schedules and costs
  - Manpower: numbers and skills

TASC

Lockheed Martin provided a generic list of activities that they followed in preparing for the restart of the C-5B, as well as other aircraft. In addition to restarting the C-5, Lockheed Martin has restarted the manufacture of the P-3 aircraft at its Marietta, GA, facility (following initial production in California). This checklist, equally applicable to the B-2, is summarized below. The list delineates the range of activities necessary to begin manufacture of an out-of-production aircraft:

1. Refine configuration of last aircraft produced.
2. Obtain bill of materials and cost data from last lot.
3. Determine major changes to "make" for restart aircraft.
4. Review all available supplier data to determine critical suppliers for restart.
5. Determine which suppliers are no longer in business, have merged, have been acquired, or have moved to a new location.
6. Hold preliminary make-or-buy meeting.
7. Determine potential suppliers for new items or for items requiring new suppliers.
8. Determine lot sizes, master schedule, and pricing groundrules for new program.
9. Program request for proposal (RFP) to obtain supplier proposals in order to determine ability to meet cost targets and/or to select new suppliers.
10. Prepare activation schedule.
11. Establish plans for first article master schedule committee.
12. Determine manpower requirements and select key management personnel.

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Restart Lessons Learned

- **B-1B restart: faster, less costly**
  - Continued development, tests, studies, IR&D
  - Detailed key personnel planning
  - Detailed vendor/supplier/subcontractor planning
- **C-5B restart: faster, less costly**
  - Potential restart was planned
  - Tooling maintained in production readiness
  - Facilitated by C-5A re-winging
- **Restart vs. new start (general conclusions)**
  - Lower risk
  - Shorter development time
  - Lower program cost
  - Lower investment cost

Historically, restarts have proven to entail lower risk, lower cost, and shorter schedules than a new program

TASC

While there is no current plan to restart the B-2, there have been other unanticipated aircraft program restarts in the past. Neither the B-1 nor the C-5 is fully analogous to the B-2, but actions taken to reduce restart times and costs on these programs can provide valuable lessons for a potential B-2 restart in the future. If there is ever a requirement to restart the B-2 in the mid- to long term, lessons learned from the restart of the C-5, B-1 and P-3 indicate that having access to both government-owned and contractor-owned tooling, machines, processes/procedures, and selective long lead items is critical for a successful restart. It should be noted that, in the case of the C-141, the tooling was destroyed after production completion and this probably precluded building more C-141s.

Restarting the B-2, either in the near term (one to three years) or in the mid- to longer term (five to ten years or more) would be a major undertaking. However, history has shown that restart of major military aircraft programs can be successfully accomplished, even after many years of shutdown, if proper attention is given to preserving long-lead items (such as tooling) and planning to reassemble and activate a contractor and supplier network.

TASC's efforts were not concentrated on evaluating earlier restart programs. Rather, TASC briefly examined major issues in the two restarts considered most analogous to a potential B-2 restart. These assessments confirmed the value of drawing up basic plans for a restart and maintaining expensive tooling and any unique production and test equipment. Both the B-1B and the C-5B were restarted, produced and completed with less risk, and in much shorter periods of time than would have been required for new starts and most certainly at greatly reduced costs.

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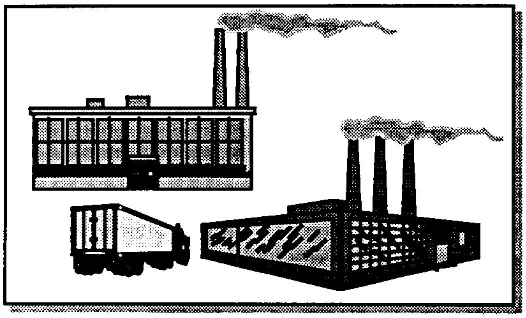
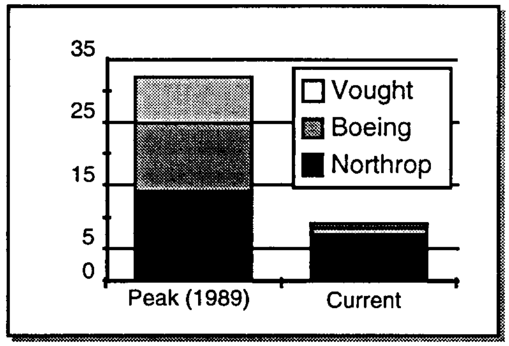
Status of B-2 Manufacturing Capability

B-2 workforce reduced 75% from peak -- ≈32,000 (1989) to ≈8,000 (today)





B-2 Employment (1000's)
Major Airframe Producers

Structures fabrication and assembly nearly complete

Major facilities being converted to other uses

About 70% of tooling is inactive

Most subcontractors finished -- some since 1992.

TASC

Although the B-2 program is still active, any decision to build more than the authorized 21 aircraft -- even in the near term -- would actually have many characteristics of a restart. B-2 production is winding down and many of the capabilities that were applied to B-2 during its peak funding years have long since been diverted. Although it is generally true that, the less time that has gone by, the fewer the difficulties programs face in restarting and achieving required rate production, there are many areas in which the B-2 must reconstitute -- not simply maintain -- essential capabilities.

A truism applicable to all completed production programs is that the associated industrial base shuts down from the bottom up. That is, the supplier bases for Northrop Grumman, Boeing, and Vought completed their deliveries in time for their products to be incorporated into the major subassemblies of the airframe. Also, since airframe components and subassemblies are less likely (than electronic or mechanical systems) to be in continued production for spares or replacement parts, there is currently a negligible level of ongoing airframe fabrication.

At the prime and major subcontractor levels, fabrication work on production aircraft is complete, to include fabrication of structural components at Boeing, Seattle, WA; the NG Vought facility in Dallas, TX; and at the NG facility at Pico Rivera, CA. All of the major structural assembly work (e.g., wing attachment) at the NG Palmdale, CA facility is also complete. Along with the curtailment of work, there has been a 70 percent reduction of personnel (from peak levels) and about 70 percent of airframe tools are inactive. In addition, Northrop Grumman is in the process of vacating the Pico Rivera facility -- which was dedicated to B-2 production -- regardless of any continuation or restart decision. Meanwhile, the NG Palmdale facility (the site of B-2 assembly) remains active and dedicated to B-2 modifications and depot work, with about 4,600 employees.

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Retention of B-2 Capabilities

- **Significant capabilities will be retained through upgrades and depot maintenance activities**
  - Block 30 deliveries and retrofits continue through year 2000 (multi-billion dollars for R&D, production, and initial spares)
  - Contractor-operated Programmed Depot Maintenance (PDM) cycle continues through 2005
  - Contractor-operated Software Integrated Support Facility (OK City)
  - Sustaining Engineering ($1B in FYDP, multi-billion beyond)
- **Some key suppliers will be supporting operation of B-2 aircraft**
- **Other future stealth aircraft in development -- F-22 and JAST**

TASC

Although final B-2 production is progressing quickly, myriad support activities will be taking place well into the next century. Activities highlighted here include the completion of production and a series of upgrades that will enable all aircraft to reach Block 30 configuration by the year 2000. No decision on additional upgrades beyond Block 30 has been made, but modifications that would continue to modernize the B-2 are plausible likely, in the light of past programs' experience.

Assembly, testing and delivery of the last eight air vehicles will take place between now and 1998. Beyond that, a significant amount of work remains to be done on the existing B-2 fleet to complete production and enable the aircraft to meet its mission requirements. For the remainder of the century and for several years beyond, there will be a moderately robust base of industrial activity upon which a production restart could build. The B-2 program has been largely "concurrent," with a substantial level of development occurring during production. Of the 21 air vehicles (AVs) in the program, only AVs 20 and 21 will be delivered in the full Block 30 configuration. (AV-1 will not become an operational bomber.)

AVs 2 through 19 -- all but two of the operational aircraft -- will be cycled back to Northrop Grumman for upgrade to Block 30. These aircraft are currently at either Block 10 or Block 20 configuration. Upgrading air vehicles 11 to 16 to Block 20 capability will take place from mid-1996 to mid-1997. Planned upgrade for air vehicles 7 to 19 to full Block 30 configuration will take place from mid-1996 to late 2000, while more extensive rework of air vehicles 2 to 6 will take place from mid-1996 to early 2000. If there are additional block upgrades, work on the B-2 could continue well past 2005. Beyond this defined upgrade program, there are other R&D activities, some production activities and, potentially, initial spares acquisition that could maintain some level of B-2 activity long after final deliveries. All of this industrial activity will be strongly reinforced by the cycle of programmed depot maintenance (PDM), which is scheduled to be performed by the contractor team into the foreseeable future.

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Future Investment in B-2

An Illustration

Estimated Cost of B-2 O&M (TY$M)

	FY96-01	Outyears	TOTAL
Fuel	1.6	10.5	12.1
Consumables	228.0	2,488.2	2,716.2
Repairables	172.4	1,449.8	1,622.2
Sustaining Engineering	1,020.8	7,210.8	8,231.6
Interim Contractor Support	371.0	54.2	425.2
TOTAL	1,793.8	11,213.5	13,007.3

Source: SAF/AQQS(B), P-5 Document for the B-2 program submitted to Congress with FY96 President's Budget

TASC

In addition to the skills that will be retained through the B-2's block upgrade program, capabilities and critical skills will be exercised through PDM and related support efforts led by Northrop Grumman. In part because these O&M requirements are being amortized over a much smaller number of aircraft than originally planned, the government's financial commitment to the B-2 is staggering. The multi-billion dollar estimate for B-2 maintenance shown above does not include the block upgrades, which are part of the B-2's production budget.

There is continued B-2 depot work scheduled for the next ten years. Contractor-operated PDM will begin in 2002 and will not be complete until 2005. PDM will retain some capabilities and critical skills at Northrop Grumman and at other B-2 contractors, such as Hughes and Loral. Software support will be contractor-furnished (by Northrop Grumman) but will be moved to Oklahoma City, OK, and will continue indefinitely. Training systems and airframe maintenance will also be contractor-furnished. Finally, sustaining engineering is funded in the Future Year Defense Program (FYDP) at about one billion dollars and is forecast to be a multi-billion dollar effort in the outyears.

Overall, these extensive activities, together with normal material support operations of the B-2 supplier base -- combined with other closely related activity in the F-22 and JAST programs -- will add to the base of expertise available for a future restart.

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The Near Term -- B-2 Preservation

- **Emphasis on maintaining near-term availability of current sources and capabilities**
- **Limited funding for such activities as:**
  - Planning
  - Key subcontractors
  - Requalification of essential sources
  - Identification/establishment of alternative sources
- **Directed at gearing up production in FY96/FY97**
- **Provides hedge against 1990s restart decision -- but no lasting value for longer- term restart**

TASC

As compared to the B-1 and other military programs that have made concerted efforts to plan for restart, the B-2 program is taking relatively few steps to prepare for this eventuality.

One of the primary actions that is being taken, known as "preservation," is geared toward retaining the option of restarting the program in the near term. Preservation is intended to preserve a production capability for B-2, with the objective of protecting reasonable cost and schedule options for additional B-2s, should the need for a larger force be identified. If a decision were made to restart the B-2 in FY96, for example, the preservation plan would have provided for the requalification of essential sources and the identification of alternative suppliers.

The preservation activity includes the requalification of suppliers, establishment of sources for critical unavailable or out-of-production parts, updating of work orders and manufacturing plans, restoration of facilities to permit major tool installation, and the proving and validation of subassembly tools.

For practical purposes, preservation activities will maintain essential elements of the production base only until a FY96 decision is made (via the authorization and appropriations process) with respect to producing additional B-2s. If there is no positive decision to produce more B-2s (or alternatively, to extend and enhance preservation funding), the "preservation" activities will end.

In FY95, Congress appropriated $125 million for B-2 preservation. The intent was to keep options open while the future of the B-2 was being analyzed and debated by Congress and DoD. It is unknown whether this activity will be continued in FY96.

However, it should be noted that the preservation activity does little (if anything) to reduce the cost and time of a restart in the more distant future.

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B-2 Curtailment

- **Current "curtailment" program**
  - Curtailment is shut down (**not** a restart plan)
  - Closes out current B-2 production program while ensuring support for remaining development, test, and operations
  - Provides interim maintenance and storage of government-owned production tools through 1997
  - Determines disposition of government-owned tooling and test equipment (e.g., scrap, transfer, sell, retain)
- **Initial emphasis is on orderly phase-down/close out of production**
- **Emphasis on ensuring ability to provide operational support for life of B-2**

TASC

A January 1992 decision reduced the B-2 production program from 75 to 21 air vehicles. The need to reduce the scale and pace of industrial operations to accommodate this change led to the development of a curtailment plan by the B-2 SPO. This plan will extend from FY93 to FY02, with annual options. The B-2 curtailment program is not and was never intended to be a "restart" program; rather, its primary intent is to achieve an orderly phase-down and close-out of the ongoing production effort and to ensure the contractors' continued ability to provide operational support for the life of the B-2 weapon system. The existing B-2 curtailment plan is based on a roadmap that shows the last supplier production in 1996, last flight test completion in July 1997, and the last Block 30 B-2 delivery in the year 2000.

Curtailment has many facets. Its major feature is protection of government-owned special tooling and test equipment. To this end, the curtailment program has thus far screened government property used in B-2 production for retention as required for life cycle support. Over 126,000 tools have been screened for entry into the curtailment inventory. (However, this limited activity does not constitute a comprehensive effort to maintain and store tooling that would be required for a restart.)

Another function of the curtailment program is to preserve a production capability for spares, including tools and design data. Curtailment further preserves airframe depot capabilities for airframe repairs and surface preparation. Level III drawings and procurement data are retained, and production tooling is preserved at least through 1997. Finally, curtailment includes the disposal of property not required for the program, and data disposition/retention.

A decision will be made at the end of 1997 concerning the disposition or permanent storage of special test equipment and special tooling that is now in interim storage.

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Potential Curtailment Costs

Projected Curtailment Budget (Annual)

	93	94	95	96	97	98	99	00	01	02	Total
TY$M	31.3	25.4	26.5	15.4	15.2	11.2	11.8	15.8	4.5	2.9	160.0
95$M	32.8	26.1	26.5	15.0	14.3	10.2	10.5	13.6	3.8	2.4	155.2

Aggregate Funding for Curtailment (FY95$M)

	FY93-95	FY96-02	FY03 &Beyond
Current Approved Program	85.4	69.8	
Additional Funding for Indefinite Support			2.4 (per year)

Assumptions
- Positive FY97 decision on continuing curtailment
- Curtailment will cover 80-90% of critical items for restart
- Curtailment reverts to storage program after 2002

TASC

This chart provides the costs of continuing the current curtailment program past the current FY97 decision point. The B-2 curtailment program is the minimum in a spectrum of curtailment options, but it will preserve the ability to complete current development, flight test and production requirements. Also, while shutting down many activities associated with the B-2, the B-2 SPO and its contractors have a responsibility to provide operational support for the life of the B-2 weapon system.

The current curtailment program has a period of performance of 10 years (FY93-02), exercised on a year-by-year basis. The cost beyond FY02 is expected to average $2.4M per year in FY95 dollars. The last supplier production is expected in 1996, the last flight test completion is expected in July 1997; and the last air vehicle "production" is expected in January 1998. The last Block 30 delivery is expected in 2000.

While contractor-owned assets (e.g., tooling, special test equipment, technical data, machines) are not part of the current curtailment program, government-owned assets are included. The program is retaining property required for life cycle support, including one shipset of selected special tools and special test equipment. The property is being stored through FY97, when the Air Force will make a decision on whether to continue to retain those assets. Tool data packages are being retained with the tools. The current curtailment program also includes a process for cost-effectively disposing of property not required for the program. This includes obsolete and duplicate tools. The curtailment program does not protect the B-2's trained industrial workforce, supplier-owned facilities, proprietary subcontract processes or data and supplier- owned tooling. It also does not provide for retention of government-owned tooling not required for ongoing operational support.

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Enhanced Curtailment

- **Would augment curtailment program to reduce restart time and cost**
- **Could potentially save 1-1.5 years in a 6+ year restart program**
- **Would include key subcontractors and suppliers**
- **Would begin with a detailed cost/benefits analysis**
  - Layaway/storage government-owned tooling
  - Plan for long-lead procurements
  - Assess potential costs/benefits of acquisition of depreciated contractor owned tooling and test equipment, to include all critical suppliers
- **Level of "enhancement," and, therefore cost, can vary greatly**

TASC

Curtailment is defined as the process of cutting back and eventually shutting down B-2 production. Although it is not specifically directed at a shutdown or restart, curtailment nevertheless offers some ancillary benefits for restart. At very modest cost, we estimated that Northrop Grumman's existing curtailment plan could be enhanced to provide capabilities that have been characterized by other programs as "smart shutdown." Extension of the curtailment plan to promote "smart shutdown" would be a relatively inexpensive insurance policy that would provide an option for a more expedient restart in the future.

We have used "enhanced curtailment" to describe various activities that facilitate program restart. The term encompasses actions that can be done at a nominal cost (e.g., planning) as well as those that require a more substantial investment, potentially over a period of many years. In some programs, for instance, enhanced curtailment has included videotaping (and narrating) all critical manufacturing tasks to ensure that as much as possible of the process technology is preserved for the future. For the B-2, this would be an expensive undertaking, but, more to the point, it already is too late: most critical processes have already been completed. In still other programs, the term has been defined to include the procurement and storage of long-lead component, such as large castings and forgings.

For the B-2, the purpose of "enhanced curtailment" (or "smart shut down") would be to enable more effective reconstitution of production capability at some future time. In addition to the steps already taken by the existing curtailment plan, enhanced curtailment might include the protection (through government acquisition) of selected, unique, contractor-owned equipment, such as some of the special, very large composites structures fabrication and inspection equipment at Boeing. Such equipment is extremely expensive and difficult to replace. Lists of critical materials and key personnel might be retained, and some critical long-lead materials, such as large forgings, might be acquired. Some of the items only partially protected in the curtailment plan would be more fully protected in enhanced curtailment.

The cost of an enhanced curtailment program could vary widely, depending on such variables as the number and type of equipment that is acquired and stored, the amount of proprietary data purchased from contractors, and the length of time that these assets will be stored.

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Cost of Enhanced Curtailment

	FY95$M		
	FY93-FY95	FY96-FY02	FY03 and Beyond
Curtailment (Current)	85.4	69.8	2.4 per year
Plus Enhancements	0	100.0* (Order of Magnitude)	1 - 3 per year
	85.4	169.8	3.4 - 5.4 per year

* Long-lead (Forgings and Materials)	25
* Contractor-owned Equipment	50
* Special Tools/Test Equipment (Contractor-owned)	25
	100

Assumptions

- **Continued funding of curtailment plan**
- **Curtailment (current and enhanced) covers up to 100% of critical items for restart**
- **Curtailment (current and enhanced) will save 1 - 1.5 years in restart**

TASC

The current B-2 curtailment program does not protect the B-2's trained industrial work force, supplier-owned facilities, proprietary subcontract processes or data, and supplier-owned tooling. While the current B-2 preservation program has as its objective the preservation of the option to produce more B-2s starting next fiscal year, it does not include the government's purchase of critical contractor-owned assets in the event that current production is not extended.

As noted in the previous chart, the cost of an enhanced curtailment program can vary considerably, depending on the amount of "insurance" that decision makers consider necessary. The cost estimates for the $100 million enhanced curtailment program shown above are based on interviews with B-2 managers as well as those involved in restarting the B-1 and C-5. The cost range was estimated at $100 million to $300 million and the low end of the range was selected for use in developing subsequent restart estimates. This program includes funds to procure long-lead items such as titanium forgings and castings used in Boeing's Aft Center Fuselage section and Nicalon fiber mats. It also includes selected contractor-owned machines, and special tools/test equipment. Examples of this type of equipment include a Cord Stringer Tool, Composite Edge Factory, and a 10-axis Automatic Thru Transmission Unit (ATTU).

This is not an all-inclusive list of investments, but it does provide insight into the magnitude and range of activities that could be undertaken to preserve a restart option. Their goal is to buy back 1 to 1.5 years of schedule so the first aircraft in a restarted B-2 program (i.e., AV-22) is built and delivered in 6.25 years -- a half year less than the current build time. It is assumed that the contractor-owned items can be acquired by the government at depreciated prices. If the investment is not made soon, there is a very real potential that the contractors that own the equipment will use it on other programs or dispose of it to free their facilities for other uses. If a decision is made to restart and the contractors have neither retained the assets nor can be convinced to procure the capital equipment one more time, then the government would have to purchase the equipment at a much higher price than today's, and also pay the price of lost time.

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Restart Groundrules and Assumptions

DEFINITIONS

Recurring flyaway cost

- The recurring cost of producing the aircraft, management, and engineering change orders

Aircraft flyaway cost

- Adds non-recurring cost: production restart

Weapon system cost

- Adds technical data, support equipment, and training equipment

Procurement cost

- Adds initial and mission readiness spares kits

Program acquisition cost

- Adds program's research, development, test, and evaluation (RDT&E) and facilities costs

Life-cycle cost

- Adds project operations and support (O&S) costs over twenty-five years

TASC

The following pages summarize the results of our analysis of the life cycle costs (LCC), schedules and risk of restarting B-2 production. The cost-estimating methodology is described in detail in Appendix A. The estimates differ from those generated by Northrop Grumman, the Air Force, the OSD CAIG) and IDA in that our analysis is based on a much later restart decision -- an initial go-ahead in FY04 and production decision in FY07, as compared to FY97 in the other analyses. While a production decision, especially in the FY07 time frame, is far from certain, the intent of the analysis is to develop a sense of the resource implications of a later decision.

The ground rules and assumptions used in our analysis include the following:

- Costs include LCC for 20 additional B-2s, with a 25 year service life
- Current and enhanced curtailment will be funded until the start of the restart program
- All costs use the latest OSD (Comptroller) inflation rates and are in FY95 dollars
- The cost of the first 21 aircraft (plus the static and fatigue articles) and the cost to upgrade 18 aircraft to the Block 30 configuration are considered sunk and are not included in this estimate
- Costing assumes that there will be no major upgrades beyond Block 30, since no post-Block 30 upgrade plans have been specified. However, we have included an allowance for engineering change orders (ECOs) for routine changes for the buy of 20 additional aircraft
- A restart decision will be made in FY04. Long- lead funds will be authorized in FY05 and FY06. Production will be authorized in FY07. First delivery will be in FY12 and the last delivery will be in FY19. The production rate will be at 3 aircraft per year
- No RDT&E will be required since the aircraft will all be built to the Block 30 configuration. Any non-recurring effort will be funded with production funds
- All contracts will be Firm Fixed Price (FFP) and will meet the requirements of the FAR.

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Life Cycle Cost of Additional B-2s

(FY95$B)

Cost Element	Alternative 1 (Low Estimate)	Alternative 2 (High Estimate)
Aircraft Production (Recurring)	17.5	18.4
Government Management	0.8	0.8
Allowance for Changes	0.9	0.9
Recurring Flyaway Cost	19.2	20.1
Non-recurring Start-up	0.2	1.6
Aircraft Flyaway Cost	19.4	21.7
Support Equip, Data, Training	0.6	0.6
Weapon System Cost	20.0	22.3
Initial Spares	1.3	1.4
Procurement Cost	21.3	23.7
Facilities	0.3	0.3
RDT&E	0.0	0.0
Program Acquisition Cost	21.6	24.0
Operations & Support (25 years)	9.6	9.6
Life-Cycle Cost (Before Risk)	31.2	33.6
Life-Cycle Cost (Including Risk)	32.4	

This chart shows the components and "bottom line" cost of 20 additional B-2s, given a restart go-ahead in FY04 and production decision in FY07. The estimate is based on the cost of the 100th aircraft, extended over a 20-aircraft buy. Averaging out "low end" and "high end" estimates (see Appendix A), the cost of the procurement would be about $32.4 billion in FY95 dollars. This estimate is roughly comparable to the $44-billion price tag (then-year dollars) for the purchase of the first 20 aircraft, when major differences are taken into account. The most significant differences are the inclusion of 25 years of O&M in the new estimate, the high level of R&D spending (about $24 billion) in the original program costs, and differences in valuation (FY95 dollars used above versus then-year dollars for the current program).

The estimate shown above assumes that steps were taken under the current and enhanced curtailment program to maintain important elements of the industrial base and otherwise keep B-2 restart options open.

It is important to note that the $32.4 billion restart estimate is relatively close to those generated for an earlier time period by Northrop Grumman, the Air Force, the CAIG and others. Thus, **it appears that the option of waiting does not have severe cost penalties associated with it, provided that "smart shut down" actions begin in the near term and continued until restart begins.**

DRAFT

Schedule for More B-2s

	Year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Restart Decision *Program Go-Ahead*	X															
Long Lead		X	X													
Procure Qtv (20) Number of Aircraft				2	2	3	3	3	3	4						
Deliver Qtv (20) Number of Aircraft									2	2	3	3	3	3	3	1

TASC

Year 1, followed by the purchase of long-lead items during the next two years. Under this scenario, deliveries would begin in Year 9 and would be completed in Year 16. The production and delivery profile was adapted from information provided by Northrop Grumman, and is believed to be reasonable by the study team. However, it is generally believed that the longer the gap in production, the longer the time between go-ahead and first delivery.

The hypothetical restart schedule is assumes that few changes will be made from today's Block 30 aircraft, with an addition of 5 percent more funding and time for engineering changes. This allowance for changes is considered to be modest. The B-2 technology could easily be 20 years old by the time restart deliveries begin, leading to inevitable pressures for modifications and upgrades. Given the longevity of the B-52 and B-1B aircraft, and the savings in development costs over a new bomber, a B-2 restart may be a viable option for meeting mission needs into the next century -- even if more extensive non-recurring investment is needed to produce a modernized capability.

Nevertheless, the schedule highlights the fact that a B-2 restart cannot provide the government with a means to respond to an emerging threat or crisis by obtaining additional bombers quickly. The first deliveries are likely to begin long after the problem at hand is resolved. The chief alternative to a restart -- a newly designed bomber -- is discussed in the next section.

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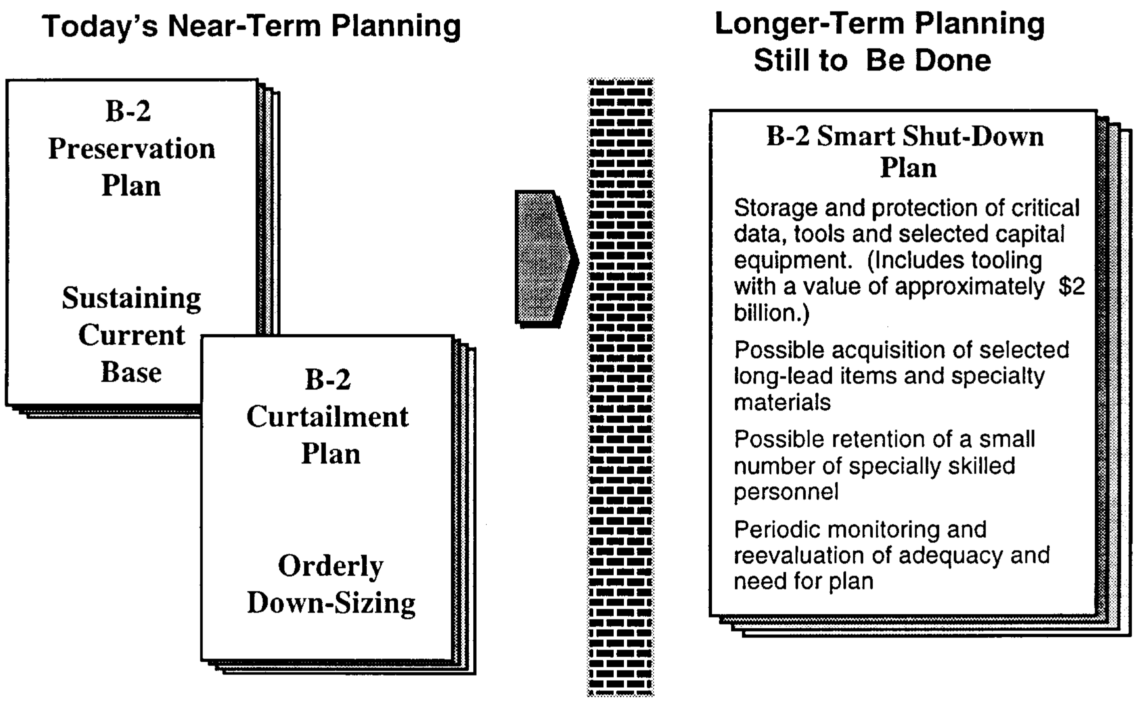
Conclusions About Enhanced Curtailment



Based upon DoD's decision to not purchase additional B-2s at this time, we believe that a "smart shutdown" plan should be prepared and implemented in an evolutionary manner, at least initially at modest expense, to preserve the most critical capabilities and to reduce risk in restarting production. A future restart might be desired after the Block 30 aircraft have been operationally proven, if a decision is made to modernize the bomber fleet or if the threat environment changes demonstrably. Northrop Grumman's current B-2 preservation and curtailment plans, although thorough, are only funded through 1997 and do not adequately address the objectives of a smart shutdown. Findings regarding smart shutdown are based on the following assumptions:

- The remaining work during the next ten years, to bring the initial 20 B-2s to the Block 30 configuration and to perform additional PDM work, will retain many critical integration and software skills and much of the assembly capability needed to restart production
- In the absence of significant design changes, the delivery schedule for a future restart will not greatly exceed those recently proposed by Northrop Grumman -- a rate of 1-1/2 to 3 aircraft per year. (Even for near-term production, it would be necessary to restart most of the fabrication capabilities, because Boeing and Northrop Grumman-Vought have completed most of their work, and have reassigned or lost most of the personnel who worked on B-2)
- The aircraft industry will maintain sufficient stealth and other critical technology capabilities as a result of the continuing work on B-2 and programs such as F-22 and JAST
- Excess aircraft industry capacity will exist and minimize the cost of facilitization for restart (Retention of important Air Force-owned facilities will help maintain capacity)
- Northrop Grumman and most of its key suppliers will retain a core capability of their highly skilled personnel with B-2 expertise, although they may be reassigned to other programs
- Future B-2 production is unlikely to suffer much of a learning disadvantage compared to its initial production. The small initial quantity of B-2s has precluded significant learning gains.

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B-2 Restart: Task 2 Findings

- **Industry has the capability and experience to restart B-2**
  - Experience with restart of several military programs
  - B-2 prime contractor will have continued depot involvement through 2005 and major mods currently planned through 2000, with long-term maintenance plan to be defined later
- **Restart time and costs could be reduced through enhanced curtailment program**
- **Would require funding above the current cap (about $10 million initially)**
  - Possibly lower recurring cost level)

TASC

Today's decision on continuing the B-2 hinges on a number of factors, not the least of which are the cost of additional aircraft and their uncertain military utility in today's world. Nevertheless, there are many reasons why a restart could occur. Although the complexity of the B-2 would make a restart program one of the most ambitious ever undertaken, essential capabilities will continue to reside in the aircraft base and there are no insurmountable hurdles to a successful restart. Restart experts who managed the B-1 and C-5 restart programs agree that, like many other aircraft programs, there are no major impediments to a successful restart of the B-2.

Cost and schedule will, however, be important factors in a restart decision. Experience has repeatedly shown that a modest investment to close out a program systematically and maintain access to critical long-lead items will have important payoffs if a restart occurs. The B-2 program has been formally cut back to only 21 aircraft, but continuing advocacy for an expansion of the existing program has reduced any incentive for a well-planned shutdown. As the current program progresses toward its conclusion, capabilities are diminishing without sufficient thought to their future importance to a restart program.

All evidence indicates that attention to a potential restart is needed now, while effective action is possible. Although the restart of the B-2 is currently considered unlikely, there is ample reason for DoD to "hedge its bets" and keep the restart option open for the future. If these steps are not taken, a restart would begin from the ground up, without benefiting from learning or past investments, driving cost and schedule beyond acceptable limits. Northrop Grumman's existing curtailment program must be maintained and directed toward shutdown/restart needs.

Potential Next Generation Bomber

This section describes the B-2s impact on the technologies and production capabilities that will be required for a next generation bomber.

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Uncertainties About Future Bomber

- **Industrial uncertainties**
  - Timing
  - Status of R&D and technology base
  - Status of industrial capabilities
- **Force uncertainties**
  - Remaining service lives of B-52s and B-1s
  - Mission requirements
- **Bomber design choices**
  - Range from heavy bomber to all-new concepts

Given uncertainties, excursions are prudent

TASC

The final area of investigation in this study identified and assessed issues affecting industry's ability to produce a next-generation bomber. More specifically, the decision to terminate the B-2 program after 21 aircraft, coupled with a decision not to restart the B-2, could result in a gap of at least a decade (and perhaps two) in bomber production. This raises a particular concern about industry's ability to continue technology development in areas of particular importance to bombers.

There are many uncertainties about the nature of the next bomber, when it will be produced, and in what quantity. For example, previous sections have stressed the extent to which the B-2 was driven by stealth requirements, but there is no assurance that this technology will be nearly as important when the next bomber is conceived. Rather than speculate on industrial capabilities to support specific heavy bomber options, this limited analysis took a more generic approach. In addition to its overall industrial assessment, the team examined the potential contribution of current and planned technology programs to a future heavy bomber program and performed a series of cost analyses for heavy bomber alternatives. The cost estimates were used to compare the cost of a hypothetical new bomber with those of the current and restarted B-2. Bomber characteristics used for cost estimating purposes can be found in Appendix A, but the bomber concept defined in the analysis is sufficiently generic to include a broad range of aircraft meeting fairly diverse mission needs.

The cost analysis for the next-generation bomber included two excursions.. The first analyzed the impacts of current and planned acquisition reform measures on schedule and costs, and the second hypothesized the savings that could be achieved through a manufacturing-oriented "affordability R&D" program. That program is assumed to begin immediately as a relatively modest R&D effort and continue on to system development of the new aircraft.

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Industrial Capabilities for Future Bombers

- **Various options for expanding future bomber force:**
  - Upgrade programmed aircraft (current strategy)
  - Add more B-2s or a major mod version (Restart)
  - Initiate a new manned penetrating bomber program
  - Field a long-range, high-capacity standoff weapon launch platform
  - Other government and industry concepts
- **Different concepts may tap different industry capabilities (e.g., a standoff option places greater reliance on weapons capabilities than on airframe)**
  - *Data suggest existing industry can support all options*
  - *Without "affordability" program, traditional cost growth will persist*

TASC

Given the uncertain nature and timing of a decision to develop and produce a new bomber, a definitive assessment of industry's ability to support such a program is not possible. Nevertheless, three points can be made. First, there is no evidence that a continuation of the B-2 program beyond the programmed 21 aircraft will have any positive effect on industry's ability to build a new bomber in the future. Continued production of B-2s would restore and requalify a supplier network -- but one that has only proven its ability to produce a B-2 based on mid-1980s technology. There is no assurance that these same companies would be involved in a future bomber program, or that the requirements of such a system would bear a meaningful resemblance to B-2. B-2 production would also do little to sustain critical design, development and integration skills that would be of paramount importance in a new system. A decision to buy more B-2s now will result in more B-2s -- not stronger capabilities to design and produce a future bomber.

Second, the aircraft industry has been responsive to DoD's needs in the past, and monitors these needs as a matter of business survival. Regardless of technical challenge -- which was possibly pushed to the limit by the B-2 -- industry has repeatedly demonstrated its ability to assemble a team that can meet the requirement, albeit at a greater cost and longer time than desired. Engaging leading aerospace firms in requirements formulation and concept definition will allow industry to "think ahead" and create new capabilities that are not otherwise active within the base. The size, duration and profitability of a large aircraft program -- at a time when there are fewer programs than before -- makes responsiveness an essential ingredient in business success. As long as a procurement appears profitable, aircraft contractors do not routinely turn down work because the challenges are too great, and they are less likely to do so in an austere budgetary environment for defense.

The third point is that the pending reduction in both government and industry R&D causes uncertainty that new technologies will be created and sufficiently matured to allow insertion into the next bomber. Technologies of interest to the bomber community are being worked under DoD R&D funding and the F-22 and JAST programs. Although fighter attack and bomber technologies differ, JAST and F-22 are essential to moving many bomber-related technologies ahead. It is also necessary to extend this work so that it applies equally to the scale, complexity and performance requirements of bombers.

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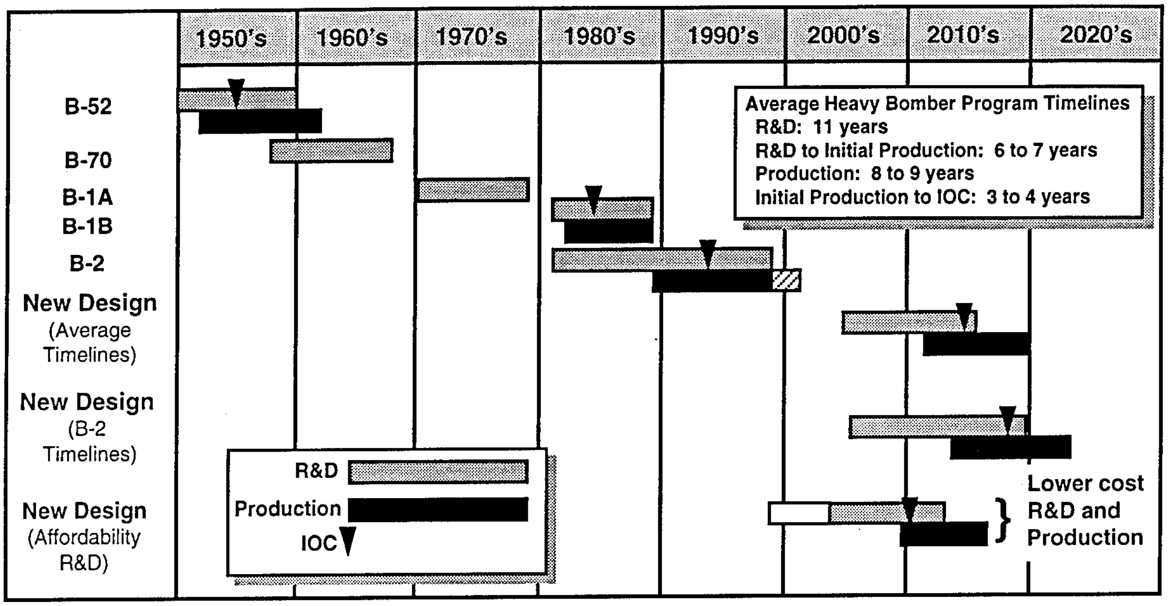
DoD Experience In Large Bomber Aircraft

Bomber Development and Production Timelines



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Will the next bomber follow the patterns of past bombers? This chart depicts R&D and production timelines for almost 50 years of bombers, and projects the hypothetical schedules of future bombers as well.

With the exception of a few relatively brief gaps (between B-70 and B-1A, and between B-1A and B-1B) , heavy bomber R&D has been continuous since 1950. The average duration of the five heavy bomber R&D efforts has been 11 years, while the average duration of the three heavy bomber production programs has been between 8 and 9 years. Given IOC dates of 1955 for the B-52, 1985 for the B-1B, and 1994 for the B-2, the average period between initiation of production and IOC is between 3 and 4 years.

Although the sample is small, it has been used to generate hypothetical timelines for three new bomber scenarios. The first schedule is based on straightforward extrapolation of the data. Assuming that the earliest start of a new heavy bomber program is FY05 (due to such factors as budget constraints), a new bomber could reach IOC between FY14 and FY16, with final deliveries between FY19 and FY21. Using only the B-2 timelines as representative results in an estimate of FY13 for initial production, FY18 for IOC, and FY23 for final deliveries. (The patterned areas on the chart extend B-2 production from 10 years to the full 12 years needed to bring all aircraft to Block 30). Thus, if there were widespread political agreement in favor of a new bomber and resources on the order of those put forth to develop the B-2, the new aircraft would be integrated into the Air Force heavy bomber fleet between FY20 and FY25, well after the B-52's fiftieth birthday (and presumed retirement).

The length of these timelines underscores the importance of reducing schedules and costs. The chart also includes a notional new bomber timeline that incorporates savings that are expected to be achieved in that time frame from acquisition reform measures.

The final estimate is based not only on planned acquisition reform measures, but on a more intensive and focused affordability program as well. This program, discussed in more detail on later charts, involves new approaches to design and production as well as traditional acquisition reform.

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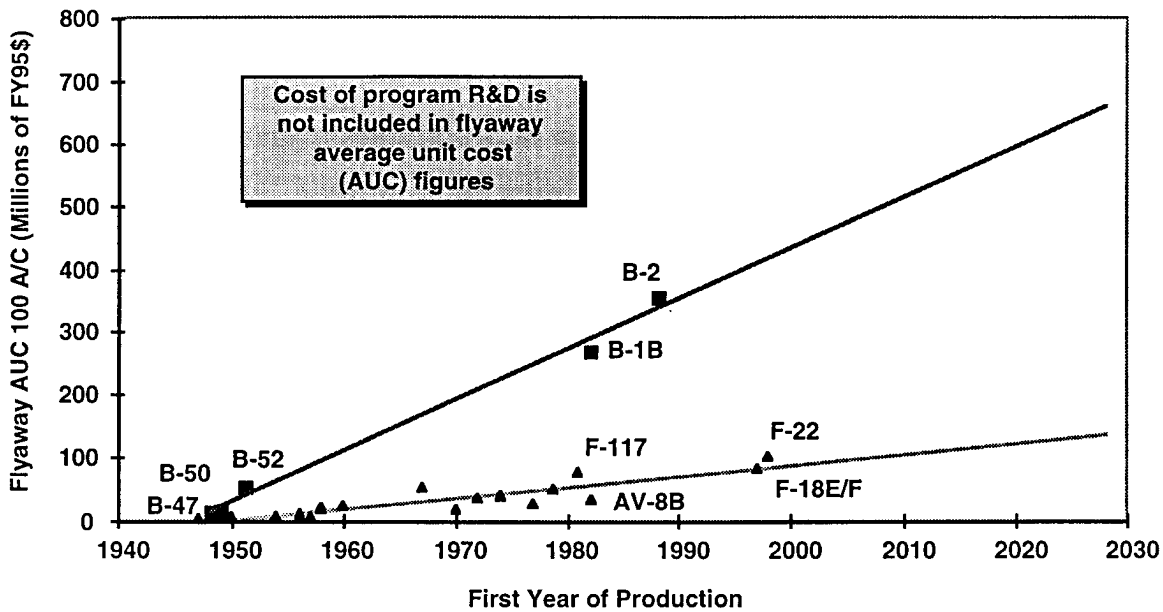
Heavy Bomber and Fighter Cost Trends



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In contrast to development and production times shown on the previous chart, which have been relatively stable over the past fifty years, both cost and performance of military aircraft have been increasing in a predictable way. The trend lines in this figure show how costs of heavy bombers and fighters are growing from generation to generation. Moreover, heavy bombers are on a steeper cost growth slope than fighters.

The heavy bomber and fighter cost trend data shown on this chart were gathered from a TASC data base and from the Seventeenth Edition of the "U.S. Military Aircraft Data Book, 1995", by Ted Nichols and Rita Rossi. The data were normalized in 1995 dollars (using the latest DoD inflation rates for aircraft procurement) for the non-recurring and recurring flyaway average unit cost (AUC) for the first 100 production units. The AUC was plotted at the point of the first year of production. The insert notes that program R&D costs are not factored into the flyaway AUC costs, but, following traditional patterns, they are indeed a major portion of the affordability equation. The R&D costs associated with any new bomber program predictably will be proportionally as great as those for the B-2, unless affordability measures are implemented to reduce the traditional costs.

Although costs of both fighters and bombers are increasing, fighter costs have increased at a much slower rate. Projected costs of the F-22 and F/A-18 E/F are shown to be in the same general range as the F-117 (in constant dollars); however, expected cost growth of these new aircraft would change the cost profile for fighters considerably. As with many aircraft, an initial aircraft design seldom remains stable; requirements and "technology push" tend to add complexity and cost to the original system.

Bombers reflect an extremely sharp cost increase from generation to generation, culminating in the B-2, whose cost is noticeably higher than its predecessor. The lesson here is that the "curve" must change radically if the next bomber is to be affordable, even in a much more generous budgetary environment. If the next bomber follows the trend line, it will be substantially cheaper to restart the B-2 than to invest in a new system. The cost of a new bomber compared to a B-2 restart will be even more dramatic if R&D costs are factored in.

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Affordability R&D for Next Bomber

- **The ability to build any heavy bomber in the future is threatened by increasing costs**
  - Even with acquisition reforms, R&D and production for next bomber projected to cost $70 billion
  - Acquisition reform essential but unlikely to have sufficient impact on costs
- **An "affordability R&D" program may prevent a next-generation bomber from following historic cost trends**
  - Heavy bomber affordability R&D program would emphasize risk reduction, low cost, and design-for-manufacturing
  - Program could potentially be structured as a complement to JAST
    - Added R&D cost (for the bomber-unique affordability design effort) would be moderate -- initially under $10 million/year

TASC

Any discussion of a next generation bomber must start with affordability. Although there are many factors that mitigate against production of more B-2s, the $44.4 billion cost of the initial 21 aircraft buy (which includes ≈$24 billion for R&D), with many more billions required for O&S, was a major consideration in DoD's decision to limit further buys. In the past, performance (and cost) have been driven by the growing sophistication of the threat, but evidence suggests that affordability limits have been reached, and often exceeded.

The idea behind an affordability R&D program is not to cut performance to bring the costs into line, backing off on the nation's long-standing commitment to qualitative superiority, but to reduce costs by designing and producing systems in a smarter way, taking advantage of appropriate manufacturing technologies, applicable commercial practices, civil-military integration, and acquisition reforms.

The affordability R&D program recommended by the study team involves an effort to find more affordable ways to develop, transition and apply technologies that are likely to be required for a next-generation bomber. This effort would help to sustain an active R&D base during a potentially extended gap in bomber production, and break the cycle of escalating weapon system costs by ensuring that the next bomber is not more expensive than the last. It could be conducted in close coordination with JAST development activities to centralize and leverage all national efforts in affordable aircraft R&D. The study concluded that a modest investment (about $10 million) to define concepts and build affordability into ongoing research would be beneficial. The annual budget for this affordability R&D program would be revised upwards as the likelihood of a next-generation bomber increases. Ultimately, should it be decided to go ahead with the next-generation bomber, this effort would transition into the next bomber's R&D phase, cutting time and money from a traditional "standing start" R&D program.

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Cost and Schedule Summary

Heavy Bomber Investment Options (20 Aircraft)

Current Curtailment $70M (FY96 - 02) + $2M/yr (FY03 and beyond)

Enhanced Curtailment Above+ $100M (FY96 - 02) + $1M-3M/yr (FY03 and beyond)

(FY95$B)	LCC*	Aircraft Cost**	Last Delivery
More B-2 Production	$32.4B	$0.89B	FY19
Next-Generation Bomber (Including RDT&E)	$68.1B	$0.87B	FY24 - FY32

* Life-Cycle Cost
** Recurring Production Cost

TASC

As noted earlier, the first-order estimates of cost and schedule developed in the analysis are based on a number of major assumptions with respect to technical features, timing, availability of resources, implementation of acquisition reforms and more.

The resulting estimates are based upon assumptions that may be substantially valid or, at the other extreme, ultimately bear no resemblance to circumstances that actually evolve over the next decade or more. Nevertheless, the methodologies and assumptions applied over several "sets" of estimates are consistent from one to the others and provide confidence that relative magnitudes are valid. (See Appendix A for details.)

The chart illustrates the relative cost and schedule implications of a B-2 restart versus a next generation bomber. The total costs are for the production of twenty operational aircraft. The estimates for the B-2 restart also assume that an enhanced curtailment program was implemented and, at a minimum, all key production equipment and at least one set of both government and contractor-owned tooling and unique test equipment was stored and maintained. The cost of the enhanced curtailment is quite modest relative to the benefits provided in a B-2 restart effort. Both the B-2 restart and next-generation bomber estimates assume that planned technology development activities continued through JAST, the F-22, or related aircraft development programs.

The difference in cost and schedule of the B-2 compared with the cost and schedule of the new bomber is compelling. Mostly attributable to the large RDT&E investment required for the new program, the total LCC of the new program is more than twice that of a restart, even under the optimistic assumptions of reduced cost resulting from acquisition reform, etc. The differences in schedule (i.e., delivery of the last of 20 aircraft) are noteworthy also.

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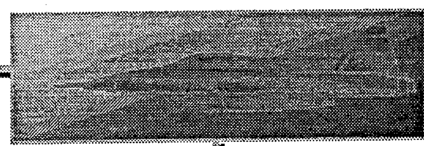
An Example: Leveraging JAST Technologies



Propulsion
- Reduce engine volume and RCS
- Simplify design

Maintenance and Support
- Improved LO durability and maintainability (Coatings)

Weapons
- Improve precision strike capabilities
- Improve lethality (blast, fragmentation, and penetration)
- CEP reduction

Avionics
- New data bus design

Airframe/Structure
- New Materials and manufacturing technologies for integrated LO structural components

TASC

It is important to maintain design capabilities for a next-generation bomber or a longer-term restart of the B-2, and this must be accomplished in an environment where there are fewer government R&D dollars and no active bomber programs. It will be necessary for future bombers to build on the development activity associated with the Air Force's F-22 fighter and the new JAST program. These programs are specifically directed at next-generation technologies required for advanced, but affordable, fighter and attack aircraft, but in many cases the activities of these programs can also benefit bombers. As currently conceived, the JAST program will develop and demonstrate technologies, develop designs for Air Force, Navy and Marine Corps variants, and finally transition these aircraft activities to the Services. At a minimum, JAST could sustain some of the design and systems integration activities needed for the support of a future bomber.

Technology areas explored by JAST that have utility for future bomber design and production are listed above. Especially critical are technologies in low observables and weapons, which will not be developed or enhanced through non-military aircraft programs. More specifically, the advances in propulsion would benefit a future bomber by providing advanced engine diagnostics with improved fault/failure detection and prediction capabilities. In avionics, a B-2 restart or next-generation bomber would be able to take full advantage of evolution in both hardware and software. Finally, improvements in LO maintainability could also directly benefit a future bomber.

Since analogous efforts directed specifically at bombers are not underway and may not be pursued vigorously prior to a restart or new bomber decision, maintaining JAST (as well as the F-22) is important to our ability to maintain an adequate "bomber technology base" into the future.

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Cost Estimate for Next Generation Bomber

FY95$B

Cost Element	Alt. 1 (Low Estimate)		Alt. 2 (High Estimate)	
Aircraft Production (Recurring)	10.6		13.6	
Government Management	0.8		0.8	
Allowance for Changes	0.5		0.7	
Recurring Flyaway Cost		11.9		15.1
Non-recurring Start-up	0.9		1.2	
Aircraft Flyaway Cost		12.8		16.3
Support Equip, Data, Training	0.4		0.4	
Weapon System Cost		13.2		16.7
Initial Spares	0.8		1.0	
Procurement Cost		14.0		17.7
Facilities	1.0		2.0	
Government Management Cost	0.6		0.6	
RDT&E	37.8		45.2	
Program Acquisition Cost		53.4		65.5
Operations & Support (25 years)	8.3		8.3	
Life Cycle Cost (Before Risk)		61.7		73.8
Life Cycle Cost (After including Risk)			68.1	

TASC

The study team found no current or planned developmental program for a next-generation bomber;therefore, it was necessary to develop a basic concept in order to estimate new bomber schedules and costs. Key technical characteristics of the aircraft used in the estimates are as follows:

- Number: 20 operational aircraft
- Type: Subsonic manned penetrating bomber
- Range: 6,000 miles unrefueled
- Weapons payload: 65,000 pounds for conventional ordnance and includes the capability to launch stand-off missiles with multi-target capability from 500 miles in all conditions with a low susceptibility to countermeasures
- Technology content: Embodies significant leaps in technology, such as low observables (which account for a 20 to 25 percent increase in survivability), electronics (computers, software, electronic warfare, and radar), composites and metals, which allow airframe weight to drop 10 percent from that of the B-2
- Propulsion: 20 percent more trust than the B-2's General Electric F118-GE-110 engines.

The program cost estimate for the next-generation bomber is shown above and details of the methodology and results can be found in Appendix A. Despite the fact that the program is assumed to reap the benefits of acquisition reform (as well as improvements in performance capabilities), the costs of the new bomber are nevertheless unprecedented. One factor driving the next-generation bomber's cost is the significant R&D investment in bringing a new bomber to production.

We have recommended a modestly scaled "affordability R&D" program to keep bomber design and development capabilities alive during any gap in bomber programs and to attempt to drive total program costs down significantly. This initiative is highlighted in this section as an important way of "shifting the trend line" away from ever-increasing bomber costs.

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Next-Generation Bomber Schedule

Option I* Assumes Implementation of Defense Acquisition Reforms

	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
-RDT&E																					
Program Decision	X																				
RDT&E		X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	→				
First Flight										X											
-Production																					
Program Decision										X											
Long Lead											X	X									
Procure Qty (14)													1	2	3	3	3	2			
Deliver Qty (14)																1	2	3	3	3	2

Note: See Appendix A for additional heavy bomber cost options

TASC

The technical characteristics described on the previous page also are important influences on the development and production schedules of the next-generation bomber. Similarly, the major assumptions used to develop a notional schedule for the new bomber, shown below, also were applied in developing the cost estimates. Key assumptions include the following:

- The next-generation bomber program will place heavy emphasis on affordability, as well as achieving significant improvements in performance capabilities
- The next-generation bomber program go-ahead decision will be in FY04 and RDT&E will start in FY05
- Defense acquisition reforms will be implemented beginning in 1995
- The analysis contains two options. Option 1, shown above assumes that defense acquisition reforms are completely successful and that of the historical time line and cost growth are reduced by 50 percent. Option 2 assumes that the historical time and cost lines continue
- Schedule and cost estimates include static and fatigue articles, six aircraft produced in the Engineering and Manufacturing Development (EMD) phase, all of which will be upgraded to operational configuration aircraft, and 14 production aircraft
- Production rate builds to three aircraft per year
- Cost estimates include LCC in FY95 dollars. (The latest OSD (Comptroller) inflation rates were used)
- There will be engineering change orders for routine changes.

First flights of heavy bombers historically have occurred about six years after the start of development. The B-2's first flight occurred eight years after the start of development, and it was 13 years from the start of development to the first flight of a fully capable B-2. With the assumption of benefits derived from defense acquisition reforms, the scheduled time to the first flight of the next-generation bomber could be reduced by a year or more.

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Next Generation Bomber: Task 3 Findings

- **F-22, JAST, and/or other related activities in LO, composites and other technologies, together with B-2 maintenance activity, are expected to maintain the industrial base for critical technologies at an adequate level**
- **The aircraft industry production base is expected to be sufficiently robust to produce a potential "B-2 like" next-generation penetrating bomber in the future**
- **The engineering activity cited above will not, however, fully address the affordability issues associated with bomber aircraft**
  - With bomber programs in an indefinite hiatus, a future bomber would benefit from targeted R&D (perhaps $10 million/year initially) to improve the affordability and maturity of critical bomber technologies

TASC

The strong outlook for the aircraft industry, fueled by commercial and export sales growth, will sustain production capabilities that will be needed for military aircraft in the future. No additional actions are considered necessary to ensure that industry will respond to a requirement for a new bomber.

The second finding concerns a critical requirement to maintain a technology base in areas that are critical to bombers, and may not be required for other aircraft types. The maintenance and advancement of critical military technologies (e.g., stealth) could be slowed as fewer military aircraft enter production. For this reason, programs such as F-22 and JAST are essential to further these capabilities and maintain them in the aircraft base at the necessary level.

Since F-22 and JAST are concerned with the application of key technologies to fighters, an adjunct program may be desirable to address the specific requirements of bombers and, more importantly, to enhance the affordability of these systems. It is possible that a new bomber will be required at some point in the future (if for no other purpose than to replace aging B-52s), and it is unlikely that the nation will ever be able to comfortably afford an aircraft whose cost follows the traditional profile shown earlier. The period when bomber production is winding down is a logical time to implement a modest program to both further bomber-related technologies and to make them more affordable for the future.

Findings and Recommendations

This section presents the overall findings and recommendations of the study. It complements the findings presented at the conclusion of each of the preceding sections of the report.

DRAFT

Findings: Industrial Capabilities for B-2

- **Industrial capabilities for bombers are not unique**
  - Draw from broad aircraft industrial base
  - Extensive overlap with other military (and commercial) aircraft
- **B-2 technology, design, and production requirements are no longer new**
  - Persist and expand beyond B-2 through industry-wide application
  - Once developed and applied, can be regenerated if needed
- **Companies that are bomber suppliers show great flexibility**
  - All aircraft primes have designed and/or produced many types of aircraft
  - Aircraft suppliers typically support multiple military and commercial aircraft
- **A strong aircraft industry will improve the long-term health of suppliers that produce "cross-over" items for aircraft markets**
  - Future aircraft industry growth projected -- especially commercial/export

Cessation of B-2 production will not prevent the nation's aircraft industry from building bombers in the future.

TASC

Our findings in this area directly address the questions raised by Congress in requesting this study of B-2 industri capabilities.

First, we found that core industrial capabilities required for B-2 and future bombers will not be endangered if tł B-2 program ends with 21 aircraft. Perhaps in contrast to the conventional wisdom, industrial capabilities that ai applied to bombers are not unique to this type of aircraft. Rather, bomber programs are served by many of tł same prime and lower-tier companies that participate in other military and commercial aircraft programs. Exce for normal movements in and out of the industry, these companies will continue to exist as elements of the aircra industry for the foreseeable future, remaining available to support a B-2 restart or future bomber. Industri capabilities that support bombers will not be saved or lost by a decision on B-2 continuation.

Second, we found that B-2 technologies are no longer unique. This finding does not suggest the B-2 was other tha a major challenge for the companies that designed and built it. The B-2 was unique in the sense that it pushed tł state of the art in a number of ways. While many of its design concepts are still unlike any other, the mo innovative technologies applied to B-2 have matured and been applied to other aircraft over the past decad Participating firms have not "lost" the lessons that they learned on B-2, and have frequently applied the elsewhere.

Third, we concluded that the source of innovation for bombers and other aircraft will remain healthy. Aircra industry economic projections indicate that the downward sales trend of the last ten years is reversing; growth sales is now forecast. Aircraft primes and suppliers have shown great flexibility in undertaking new bomb programs in the past, and are likely to continue this business posture into the future. Given the diverse custom base of firms that have supported B-2, the end of B-2 production is unlikely to affect the capability to develop ar produce bombers in the future.

The bottom line of our analysis of B-2 industrial capabilities is that continued production of B-2 aircraft is not prerequisite to our ability to restore bomber production in the future.

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Findings: Future Bomber Options

- **If required, B-2 can be restarted during the next decade without inordinate difficulty**
  - Restart capabilities have been demonstrated on other DoD aircraft programs (including B-1 and C-5)
  - Essential capabilities for B-2 will still be available or can be re-created
- **Restart difficulty, time and cost are affected by decisions to "shut down smoothly" and make targeted investments in tooling and other items**
- **Specialized aircraft industry capabilities will also support design, development and production of next-generation bomber**
  - Continued investment in R&D is essential to develop next-generation technologies
    - Build on F-22 and JAST
  - Affordability is a challenge (and probable constraint)

TASC

Findings in this area address the potential impact on future bomber options of a decision to end the B-2 program. The options include a restart of the B-2 program in the mid-term and/or the design and development of a next-generation bomber.

Assuming that the aircraft industry remains healthy, the study found that needed industrial capabilities will be available to support a restart of the B-2. Restarts of military aircraft programs have become almost commonplace as defense priorities change over time. Past programs (especially B-1 and C-5) have demonstrated the feasibility and potential cost-effectiveness of restart, and there is a wide industry consensus that this experience could be equally applicable to B-2.

However, we found that the cost and time of a B-2 restart program could vary widely, depending on the steps that are taken now to prepare for this eventuality. Although the additional costs of program start-up, learning, supplier qualification and others are inevitable, a "smart shutdown" program can go far in reducing the time and cost of start-up. B-2 program managers already have a plan that entails the storage of government-owned tooling, but an enhanced shutdown that also includes purchase of selected contractor tooling and other items is needed as a hedge against restart -- however remote a possibility it may appear.

A next-generation bomber -- whatever its configuration -- will not be affected by today's decision on the B-2. The aircraft industry retains a range of capabilities applicable to bombers and will respond when and if a new bomber decision is made. One possible constraint, however, is the pace of technology development. Although F-22 and JAST are a foundation for a new bomber, these programs cannot be expected to meet all of the new bomber's needs. This is particularly true in the area of affordability. TASC estimated the cost of a new bomber program (20 aircraft) at almost $70 billion, even considering payoffs from acquisition reform. The B-2 has already demonstrated the importance of cost in future aircraft decisions, and changing the traditional aircraft cost curve is essential to the affordability and feasibility of future aircraft programs of all types.

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Recommendations

- **Industrial capabilities should not be a consideration in B-2 continuation**
  - Decision will have negligible impact on ability to design and produce bombers in future
- **Increase attention to potential restart of B-2 and make minimum level of investment in enhanced curtailment**
  - Time is running out
  - Future payoff is considerable
  - Restart option attractive when costs of additional B-2s in future and next-generation bomber are compared
- **Couple technology development for next generation bomber with aggressive affordability thrust**
  - Affordability will probably be "go/no go" decision point
  - Current DoD actions (e.g., acquisition reform) have incremental impact -- will not assure that DoD can make next-generation bomber a reality
  - Modest investment sufficient in near term

TASC

The study resulted in three recommendations.

The first recommendation is to decouple the decision on the future of the B-2 from concerns about industrial capabilities. The B-2 debate raises many critical issues, and, without any evidence that capabilities will be seriously eroded if the program ends, it is unnecessary to cloud the debate with secondary issues.

The second and third recommendations concern high-priority investment that will help to sustain and build capabilities to support a restart and next-generation bomber in the future.

The uncertainty about the future of the B-2 (and the near-term direction of the program) has distracted managers from the important task of planning for a potential restart. To be most effective, restart preparations should begin while critical capabilities are still in place. The B-2 program needs a thorough analysis of actions that can be taken now to reduce the time and cost of a potential restart sometime in the future. The results of the analysis should then be implemented through a modest program of investments, based on the cost/benefit of alternative shut-down actions.

The final recommendation concerns the need for a vigorous affordability R&D program that will significantly reduce the cost of a B-2 restart or a next-generation bomber. Both of these programs will be costly, and repeated quantity cutbacks to reduce acquisition cost will only short-change national security needs, while raising unit (and O&M per unit) costs. In the case of the next-generation bomber, it is important to pursue affordability goals in conjunction with technology development, and to transition these efforts into the design and development phase of the new program. Without a perceived need for a new bomber until well into the next century, the team believes that the required investment in affordability R&D would be modest, although it may grow as the need for a new bomber becomes a reality.

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APPENDIX A
COST ESTIMATING METHODS AND RESULTS

APPENDIX A
COST ESTIMATING METHODS AND RESULTS

This appendix presents additional detailed information on the approach we used to estimate the costs of restarting the B-2 and estimates for a Next Generation Bomber. It is important to note our Life Cycle Cost estimate of restarting the B-2 differs from estimates performed by Northrop Grumman, the Air Force, the OSD Cost Analysis Improvement Group and IDA. Our estimate was based on different assumptions, including a restart in FY05, per our study direction from the OASD (Economic Security).

B-2 RESTART LIFE CYCLE COST ESTIMATE

Ground Rules and Assumptions — The key ground rules and assumptions used to estimate the production cost of 20 additional B-2s are:

- Costs represent the Life Cycle Costs (LCC) for 20 additional B-2s, with a 25 year service life.
- The current curtailment program and enhancements to include acquisition and storage of selected contractor-owned tooling, purchase of selected long-lead items, and other measures will be implemented and funded until the beginning of the restart of the program to buy 20 additional B-2s.
- All costs are expressed in FY95 dollars. The latest OSD (Comptroller) inflation rates were used.
- The cost of the original 21 B-2 aircraft (plus the static and fatigue articles) and the cost to upgrade 18 of these aircraft to the Block 30 configuration are considered *sunk* and are not included in this estimate.
- The analysis assumes that there will be no major upgrades beyond Block 30, since no post-Block 30 upgrades have been specified. However, we have included an allowance for engineering change orders (ECOs) for routine changes for the buy of 20 additional aircraft.
- A restart decision will be made in FY04. Long lead funds will be authorized in FY05 and FY06. Production will be authorized in FY07. First delivery will be in FY12 and the last delivery will be in FY19. The production rate will be at 3 aircraft per year.
- No RDT&E will be required since the aircraft will all be built to the Block 30 configuration. Any non-recurring effort will be funded with production funds.
- All contracts will be Firm Fixed Price and will meet the requirements of the FAR. All contract funding will meet DoD funding rules.

Cost Estimating Methodology

Data Sources and Estimate Structure — Our cost estimating methodology was based on publicly available data. We received cooperation from the B-2 System Program Office. In addition, Northrop Grumman cooperated with our efforts and provided data from their Program Cost Report pertaining to the FY92/93 lot, i.e., the last lot of aircraft consisting of Air Vehicles (AV)-17 through AV-21. We also made use of historical data on past bomber programs.

We estimated the following cost elements:

- Production Costs
  - Recurring Flyaway Costs
  - Non-Recurring Start-Up Costs
  - Government Management
  - Allowance for Routine Engineering Changes
  - Support Equipment, Data and Training
  - Initial Spares
  - Facilities Costs
- Operating and Support Costs

[Note that we assumed no research and development costs are required to restart the B-2 program.]

For the larger cost elements, e.g., recurring flyaway costs, non-recurring start-up costs, and initial spares, we generated a high and low estimate. Thereby providing a range estimate. A cost risk analysis was also performed.

Estimation of Production Costs

Estimation of Recurring Flyaway Costs — We used two estimating methods to develop our recurring flyaway cost estimate. Both approaches required as input the statistical derivation of a first production unit cost of the B-2.

The development of first production unit cost at the flyaway level involved the following steps in Exhibit 1.

Exhibit 1. First Unit Recurring Flyaway Cost Estimate

Step 1: Data on historical program costs at the weapon system level for the B-2 were assembled from the *"U.S. Military Aircraft Data Book, 1995"*

Step 2: To obtain the flyaway cost we applied a 15.2% reduction to the weapon system cost. The 15.2% was based on B-1B actual cost as provided to us by Rockwell International for Engineering Change Orders (ECO), Peculiar Support Equipment (PSE), and training. ECO, PSE, and training costs are excluded from the definition of flyaway costs.

Step 3: We next reduced the flyaway cost by 8.0% to obtain an estimate of recurring flyaway cost. The 8% factor was obtained from the *"Standard Cost Factors Handbook"*, dated November 1992 and published by the Naval Center for Cost Analysis. This factor was based on 38 aircraft.

Step 4: Once we obtained the recurring flyaway cost, we normalized the data to FY95 dollars using the current OSD (Comptroller) inflation rates.

Step 5: We next divided the FY95$ recurring cost by the number of aircraft in each lot to get the average unit cost for each lot.

Step 6: We used learning curve theory to develop our estimate of T1 (the theoretical first production unit cost) and slope. We fit a curve to the average recurring unit flyaway cost by year. The curve is represented by the following equation:

$$\mathbf{UC = T1 * Q^{b}}, \text{ where:}$$

UC = the unit recurring flyaway cost,
T1 = the theoretical cost at unit 1,
Q = quantity in the production sequence, and
b = learning curve exponent: log (learning curve percentage) / log (2).

The results were a T1 of $1,173 million (FY95$) and a slope of 92% for the B-2.

We selected two estimating approaches, and developed a "high estimate" and "low estimate" to account for uncertainty. The alternative approaches are:

Alternative 1 (The RAND Corporation approach): This approach was used to generate our "low cost estimate". This approach is based upon the 1993 RAND Corporation report, *Reconstituting a Production Capability" and* reflects RAND's analysis of several restart programs. This approach proposes that the *"...follow-on programs require less time from program start to first delivery and should be significantly less expensive than the original program..." "...Restart programs experience a learning curve with a shallower (flatter) slope than that of the original production..."* Under this alternative we set-back the cost of AV-22 to production unit 7, i.e., AV-13. We also used a shallower learning curve slope, i.e., 94% vice 92% from the original program. The set-back unit and the shallower slope were based on assessing past program restart experiences and the current B-2 manufacturing program.

Alternative 2 (The Modified Schlosser approach): This method is frequently used by the Air Force. This is our "high cost estimate". The Kelsey Schlosser production gap equation considers all learning to be lost after a gap in production of 49 months. This observation was based on statistical analysis of production breaks in aircraft programs. This method was published in 1981 in a paper entitled, *Impact of Production Gap on C-Q Curve*. It is also included in the Air Force Materiel Command (AFMC) "*Cost Estimating Handbook, Volume II, Aeronautical*", Chapter 10. The actual B-2 historical experience shows that the six development aircraft had a considerably flatter cost improvement curve than the production units. Beginning the follow-on buy of B-2 production on the B-2 cost improvement anywhere prior to the first production unit would be an exaggeration. Therefore, our estimate assumed learning loss only back to the first production unit, i.e., AV-7. Given the rationale for not assuming a production restart in the realm of the development quantities, and given the rationale that all or most learning would be lost (especially production), we believe the first B-2 production unit was the appropriate set-back point on the cost improvement curve.

Non-recurring Start-Up Costs — Non-recurring Start-Up (Alternative 1): This is our low cost estimate. In the 1993 RAND Corporation report cited above, the authors stated that they observed a requirement for 10% of the original production non-recurring costs of restarted programs. According to sources at NG, this would be $210 million for the B-2 program (FY95$). (NG provided non-recurring cost for the current program in then year dollars. These dollars were converted to 1995 dollars using the OSD (Comptroller) inflation rates and the 10% value cited in the RAND report was applied to obtain the $210 million estimate.)

Non-recurring Start-Up (Alternative 2): This is our high cost estimate. Here we used a Navel Center for Cost Analysis factor from the November *1992 Standard Cost Factors Handbook*. The factor cited in the Handbook was 8% of total flyaway cost (including one standard deviation). The factor was based on a study of 38 fixed and rotary winged aircraft.

Government Management — This estimate was based on an analog to the B-1B program. The source of the analog was the July 1990 *B-1B Annual Cost Estimate*, by which time the program was essentially complete. We did not have access to the B-2 SPO estimate for government management cost. This category of cost includes government test, Systems Engineering and Technical Assistance (SETA) support, mission support, and other activities. The B-1B SPO estimate was expressed in then year dollars, which were converted to 1995 dollars by using the OSD (Comptroller) inflation rates.

Allowance for Changes — TASC's estimate was based on an analog to the B-1B program, with data provided by Rockwell International. The data was provided to us in 1995 dollars. We developed a factor from the Rockwell data -- the factor was 5% of recurring flyaway cost. The Rockwell cost was cross checked with the B-1B FY90 Annual Estimate.

Support — Support includes support equipment, data and training. This estimate was based upon an analog to the B-1B program. Rockwell International provided the data (in FY95 dollars). The nature of support items tends to relate directly to the number of aircraft being procured. Since there were 100 B-1Bs and only 20 follow-on B-2s in the potential restart program, we took 20% of the B-1B cost for support and applied it in our estimate of the B-2 restart program.

Initial Spares — This cost estimate was based upon an analogy to the B-1B program. Again, data were provided by Rockwell International in 1995 dollars. We developed a factor of 7.5% of recurring flyaway cost based on the Rockwell data.

Facilities — This estimate was based on an estimate developed by NG. It is the same estimate used by the OSD Cost Analysis Improvement Group (CAIG).

Estimation of Operations and Support (O&S) Costs — This estimate was based on the B-2 program. Information was provided by SAF/AQQS (B), from the P-5 Document that supported the B-2 program submitted to Congress with the FY96 President's Budget. The O&S estimate includes: Personnel (Officers, Enlisted, and Civilians), Fuel, Consumables, Repairables, Sustaining Engineering Support, and Interim Contractor support. We used the FY01 value from the P-5, converted it from then year dollars to FY95 dollars using the OSD (Comptroller) inflation rates, and multiplied that times 25 years. The annual O&S cost in FY95 dollars is as follows in Exhibit 2.

Exhibit 2. B-2 Annual O&S

Personnel:	
Officers (O-3)	$ 17.3 Million/year
Enlisted (E-5)	$ 59.7 Million/year
Civilian (GS-9)	$ 55.6 Million/year
Fuel	$ 0.2 Million/year
Consumables	$ 36.2 Million/year
Repairables	$ 42.1 Million/year
Sustaining Engineering Support	$170.4 Million/year
Contractor Support	$ 14.2 Million/year
Total O&S/Year	$395.7 Millionyear

Cost/Quantity Estimate Derivation — Exhibit 3 (following page) presents the data we used to develop cost/quantity curves for estimating the recurring flyaway cost for the buy of 20 additional B-2 aircraft. As discussed above, these data were compiled from the *"U.S. Military Aircraft Data Book, 1995"*.

Exhibit 3. B-2 Estimate Derivation

[COL 1] Line No.	Year	[COL 2] Weapon System (TY$M) [2]	[COL 3] Total % Reductions to Weapon For Flyaway [3]	[COL 4] Total Computed Flyaway (TY$M) [1,4]	[COL 5] Non-Recurring Percentage [5]	[COL 6] Total Computed Recurring Flyaway (TY$M) [1,6]	[COL 7] USAF Inflation Indices [7]	[COL 8] Total Computed Recurring Flyaway (FY95$M) [8]	[COL 9] Lot Quantity [9]	[COL 10] Recurring AUC Flyaway Estimated (FY95$M) [10]
1	1988	4,100	15.2%	3,479	8.0%	3,200	0.80	4,001	3	1,334
2	1989	2,796	15.2%	2,373	8.0%	2,183	0.834	2,617	3	872
3	1990	2,063	15.2%	1,751	8.0%	1,611	0.867	1,858	2	929
4	1991	2,348	15.2%	1,993	8.0%	1,833	0.904	2,028	2	1,014
5[11]	1992/1993	4,940	15.2%	4,192	8.0%	3,856	0.943	4,089	5	818
Total		$16,248				$12,683			15	$4,966
Average Per Year										$993

Footnotes:
1. TY$ = then year dollars in millions
2. From U.S. Military Aircraft Data Book 1995. Total procurement - spares = weapon system.
3. ECO, PSE, Data & Training % of Weapon System cost based on B-1B actual cost.
4. [Column 4] = [Column 2]*[1-Column 3].
5. From Standard Cost Factors Handbook. Value includes plus one standard deviation and rounded to whole percentage.
6. [Column 6]=[Column 4]*[1-Column 5].
7. Based on USAF Raw Inflation Indices based on OSD Raw Inflation and Outlay Rates Base Year 1995 Aircraft Procurement (3010/20).
8. [Column 8]=[Column 6]/[Column 7].
9. For 1988-1991 from U.S. Military Data Book 1995.
10. [Column 10]=[Column 8]/[Column 9].
11. Combined 1992 and 1993 based on information from B-2 SPO.

Two estimating approaches (detailed above) were applied to develop a range of possible outcomes, in order to capture the uncertainty in how much learning will be lost during the break in production. Data collected from the U-2 and C-5 "restarts" illustrate this uncertainty. In the case of the restart of the U-2 restarting as the U-2R, the data indicate that production cost of the first U-2R reverted to the first unit cost of the U-2. (Note: The U-2R was initially called the TR-1.) However, it should be kept in mind that the U-2R is somewhat different than the U-2, which prevented any significant degree of learning from being maintained from aircraft to aircraft. In the case of the C-5, the first C-5B started well down the learning curve -- at approximately the cost of unit 12 of the of the C-5A. In the case of the C-5B, it should be remembered that that program followed the re-winging of the C-5A and that this activity allowed greater learning to be retained.

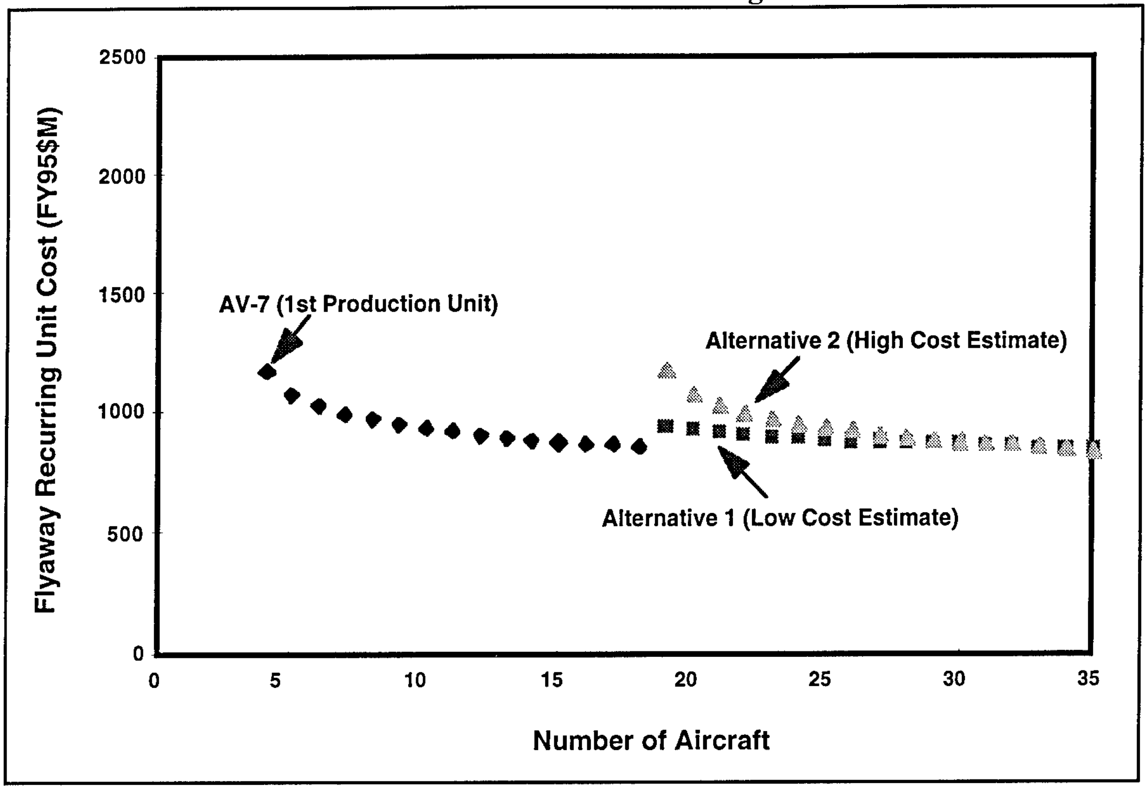
Estimated Costs of AV-7 through AV-41 — Exhibit 4 (following page) presents the estimated cost of AV-7 (the first production air vehicle) through AV-41. The exhibit is divided into four columns. Column one lists each air vehicle. Column two contains our cost estimate of the recurring production cost for AV-7 through 21. Column three is our cost estimate of the recurring production cost of AV-22 through 41 using the Alternative 1 (low estimate) costing method. Column four is our cost estimate of AV-22 through 41 using the Alternative 2 (high estimate) costing method. The cost estimate for the total program and the associated schedule are located in the text of this document (please refer to page 57). Exhibit 5 presents the Exhibit 4 tabular information in graphic form.

Cost Risk Analysis — In cost risk analysis, a probability distribution is selected to measure the uncertainty associated with a particular point estimate. A number of functional forms are available to the risk analyst; the cost risk methodology can incorporate more than 30 different distributions. Because we had only a high and a low cost estimate and it is possible that any answer in between the two could be correct. Therefore, we selected a uniform distribution.

Exhibit 4. B-2 Cost/Quantity Data Points for 35 Production Aircraft

Production Recurring Flyaway			
Air Vehicle	Unit Cost (92% Slope)	Unit Cost Alternative 1 94% Slope)	Unit Cost Alternative 2 (92% Slope)
7	1,173		
8	1,083		
9	1,033		
10	999		
11	973		
12	953		
13	936		
14	922		
15	909		
16	898		
17	888		
18	879		
19	871		
20	864		
21	857		
22		936	1,173
23		925	1,083
24		916	1,033
25		908	999
26		901	973
27		894	953
28		888	936
29		882	922
30		877	909
31		872	898
32		868	888
33		864	879
34		860	871
35		856	864
36		852	857
37		849	850
38		846	844
39		843	839
40		840	834
41		837	829

Exhibit 5. B-2 Production Learning Curves



This cost risk analysis employed a monte carlo simulation to generate a LCC estimate from the high and low cost estimates. Because we had a uniform distribution, the monte carlo simulation yields an average of the high and low estimate, i.e., $32.4B (FY95$), at the 50th percentile, i.e., the 50th percentile implies that there is an equal probability of costs being over $32.4B and an equal chance the costs will be under $32.4B. Performing a risk analysis allows for the presentation of cost estimate results with an associated probability or chance of occurrence as shown in Exhibit 6. For this monte carlo simulation we used a commercial product -- a Microsoft™ Excel™ add-on called Crystal Ball™. This application has been accepted by the Air Force Cost Analysis Agency.

Exhibit 6. Percentile and Cost Estimates for 20 additional B-2

Percentile	Life Cycle Cost (FY95$B)
0%	31.2
10%	31.4
20%	31.7
30%	31.9
40%	32.2
50%	32.4
60%	32.6
70%	32.9
80%	33.1
90%	33.4
100%	33.6

"NEXT-GENERATION" BOMBER

Our cost analysis of the Next Generation Bomber (NGB) includes the Life Cycle Costs (LCC) was developed at a macro-level based on historical bomber program cost trends. LCC is defined as follows in Exhibit 7:

Exhibit 7. Life Cycle Cost Definitions

Recurring flyaway cost	The recurring cost of producing the aircraft, management and engineering change orders.
Aircraft flyaway cost	Adds non-recurring cost: production start-up.
Weapon system cost	Adds technical data, support equipment, and training equipment.
Procurement cost	Adds initial and mission readiness spares kits
Program acquisition cost	Adds program's research, development, test, and evaluation (RDT&E and facilities costs.
Life Cycle Cost	Adds project operations and support (O&S) costs over twenty-five years.

Our cost estimate includes 6 RDT&E aircraft (plus 1 static and 1 fatigue article), 14 production aircraft and 25 years of O&S).

Background — Since World War II, the employment of heavy bombers has evolved in penetration/survivability modes and payloads/delivery modes. The following heavy bombers have been produced:

- B-17 12,730
- B-24 19,000
- B29/B-50 4,400
- B-36 382
- B-47 1,908
- B-52 743
- B-1 100
- B-2 21

The B-17, B-24, B-29, B-36, and B-50 flew at high altitude, in large formations, carried conventional iron bombs, and had defensive guns. The B-47 and, initially, the B-52 flew at high altitude in large formations, had some ECM, carried conventional iron bombs and strategic nuclear gravity bombs, and had defensive guns. The employment of the B-52 has changed over time, changing into a low altitude penetratetor and then to its current mode of being a stand-off platform. It has extensive ECM in addition to its defensive guns, and has been equipped to carry a variety of conventional and strategic nuclear weapons. The XB-70 was designed to fly at high altitude at supersonic speed, but was canceled before it went into production because of the deployed Soviet defenses against this aircraft. The B-1B is a low altitude high speed aircraft and was designed as a strategic penetrating bomber. Its role has been changed to a stand-off platform and will soon be capable of carrying several conventional munitions.

The B-2 was intended as a high altitude, low observable manned penetrating heavy bomber. It is now a low altitude, low observable manned penetrating bomber with a conventional and strategic mission. It flies subsonic in single aircraft formations and carries a mix of guided and unguided munitions. For the future, the bomber could be employed as either a stand-off aircraft with payload penetration capability or a manned penetrating heavy bomber. In either case, it will likely fly in single aircraft formations and have precision strike capability.

Changes in how bombers are employed has historically been accomplished after the aircraft was manufactured and fielded. In the case of the B-2, the employment plans were changed while the aircraft was still in development. This change caused a significant fraction of the aircraft to be re-designed. This re-design effort extended the development program, delayed the start of production and added significant cost to the program.

The B-2 is a unique airplane design and this factor contributed to its actual developmental lead time. The airframe is largely composite construction, graphite primary structure with radar absorbing composite edge treatments, to reduce weight and radar cross-section and to increase service life. The vehicle is also highly shaped with buried engines to reduce its radar signature. These configuration factors complicated air vehicle design and manufacturing and increased subsystem development requirements, e.g., autonomous flight control system and fuel system management. Outer Mold Line (OML) tolerance control and specialized exterior treatments and finishes are also utilized to reduce vehicle radar cross-section, another complexity in the comparison of the B-2 to more conventional aircraft. In April 1983, the program initiated a major redesign to accommodate revised loads and performance criteria, resulting in the current configuration. In September 1983, the decision to build a graphite composite wing, in lieu of aluminum, was made. With these advances and, most importantly, requirements for stealthy operations, the unit flyaway cost has escalated significantly from the heavy bombers of the 1950s to the B-2. The following are unique features that make the B-2 a challenge to produce.

- Air vehicle complexity and systems integration
- Large composite sections--some 75 feet long with 150 plies of composite material.
- Large titanium forgings, castings, extrusions, and super plastic formed parts.
- Tight tolerances on large composites and titanium.
- Integrated wing design with Very Low Observable (VLO) shaping.
- Low observable (LO) materials.
- Outer moldline tolerances--impacting dimensions and smoothness.
- Edge structures.
- Treated honeycomb.
- LO/hardened windshield.
- Flight control integration.
- Fuel management.
- Rapid actuators.
- Weapons integration.
- Hydraulics.
- Embedded air data system.
- Engine fan and exhaust system.
- Software code and integration--approximately 1.8 million Source Lines of Code.
- Avionics integration.
- Embedded antennas.
- LPI radar/radome integration.
- Waveguides.
- Defensive Management System.

According to Northrop Grumman data, each B-2 currently takes approximately 6.75 years to produce and deliver. Once the B-2 leaves the last assembly fixture, the aircraft requires approximately two years of final checkout before it is ready for an acceptance flight. This is a significant difference from previous generations of bomber aircraft, but they were all metal and except for very limited radar absorbing material on the B-1, they did not contain low observable features.

Technical Characteristics of the Next Generation Bomber — The Next Generation Bomber (NGB) is assumed to be a manned penetrating bomber with the following characteristics:

- **Range**: 6,000 miles unrefueled.
- **Weapons payload**: 65,000 pounds for conventional ordinance and includes the capability to launch stand-off missiles with multi-target capability from 500 miles in all conditions with a low susceptibility to countermeasures.
- **Technology content**: The NGB embodies significant technology such as low observables, which account for a 20% to 25% increase over the in survivability, electronics (computers, software, electronic warfare, and radar), composites and metals, which allow the NGB airframe weight to drop 10% from that of the B-2.
- **Propulsion**: The NGB has 20% more thrust than the B-2's General Electric F118-GE-110 engines.
- **Speed**: The NGB is subsonic.
- **Munitions**: There are significant non-guided munitions improvements in the areas of target acquisition, accuracy, and destructiveness.
- **ECM**: The NGB carries active countermeasures.
- **Reliability and maintainability:** The NGB electronics and avionics will be more reliable than those of the B-2. The engines will be more efficient and the airframe will be easier to maintain than the B-2s.

Ground Rules and Assumptions — The key ground rules and assumptions used to estimate the cost of 20 NGBs (6 development and 14 production aircraft) are:

Ground Rules and assumptions that apply to both Alternative 1 (our low cost estimate) and Alternative 2 (our high cost estimate) are:

- There will be 6 RDT&E aircraft (plus 1 static and 1 fatigue article), 14 production aircraft, and 25 years of O&S. (Note: The rationale for selecting 20 NGB aircraft was based on the desire to be able to directly compare the cost of 20 additional B-2s with 20 NGBs.)
- The NGB program will place heavy emphasis on affordability as well as achieving significant improvements in performance capabilities and reducing operation and support cost as compared to the B-2.
- Production rate is three aircraft per year.
- Cost estimates include life cycle costs (LCC) in FY95 dollars. The O&S period is 25 years. The latest OSD (Comptroller) inflation rates were used.

- There will be engineering change orders (ECOs) for routine changes.

- RDT&E contracts will be cost plus and production contracts will be fixed price. All contracts and funding will meet DoD rules.

- The NGB program go-ahead decision will be in FY04 and RDT&E will start in FY05.

The Ground Rules and Assumptions that apply only to Alternative 1 (our low cost estimate) are:

- The ability to build any heavy bomber in the future is threatened by increasing cost. An affordability R&D program will be begun in FY96 and will remain in place until the start of the NGB. It will be a risk reduction/low cost heavy bomber affordability R&D program focused on design-for-manufacturing. The goal will be to produce bombers with large fractions of composite material and low observable capabilities as economically as all metal/non-low observable aircraft.

- There will be no major requirements changes while the NGB is in development or production. Historic cost growth rate trends will be reduced 50% in both development and production.

- There will be no major design changes while the NGB is in development or production.
- Defense acquisition reforms will be implemented in 1996. These reforms will address requirements and funding instability, forcing technology into a system, absence of cost realism, unconstrained initial requirements, burdensome acquisition process, and lack of incentives to industry.

- The first flight of the NGB RDT&E aircraft will be in FY13. The production decision will be in FY13 and long lead will be authorized in FY14 and FY15. Production will start in FY16. The first delivery will be in FY19 and the last delivery will be in FY24.

The Ground Rules and Assumptions that apply only to Alternative 2 (our high cost estimate) are:

- There will be no affordability R&D program for bombers.

- There will be requirements changes while the NGB is in development and production. The cost growth trends will continue at historic rates.

- Defense acquisition reforms will not be implemented beyond those implemented by the end of 1995.

- The first flight of the NGB RDT&E aircraft will be in FY17. The production decision will be in FY19 with long lead being authorized in FY20 and FY21. Production will start in FY22. The first delivery will be in FY27 and the last delivery will be in FY32.

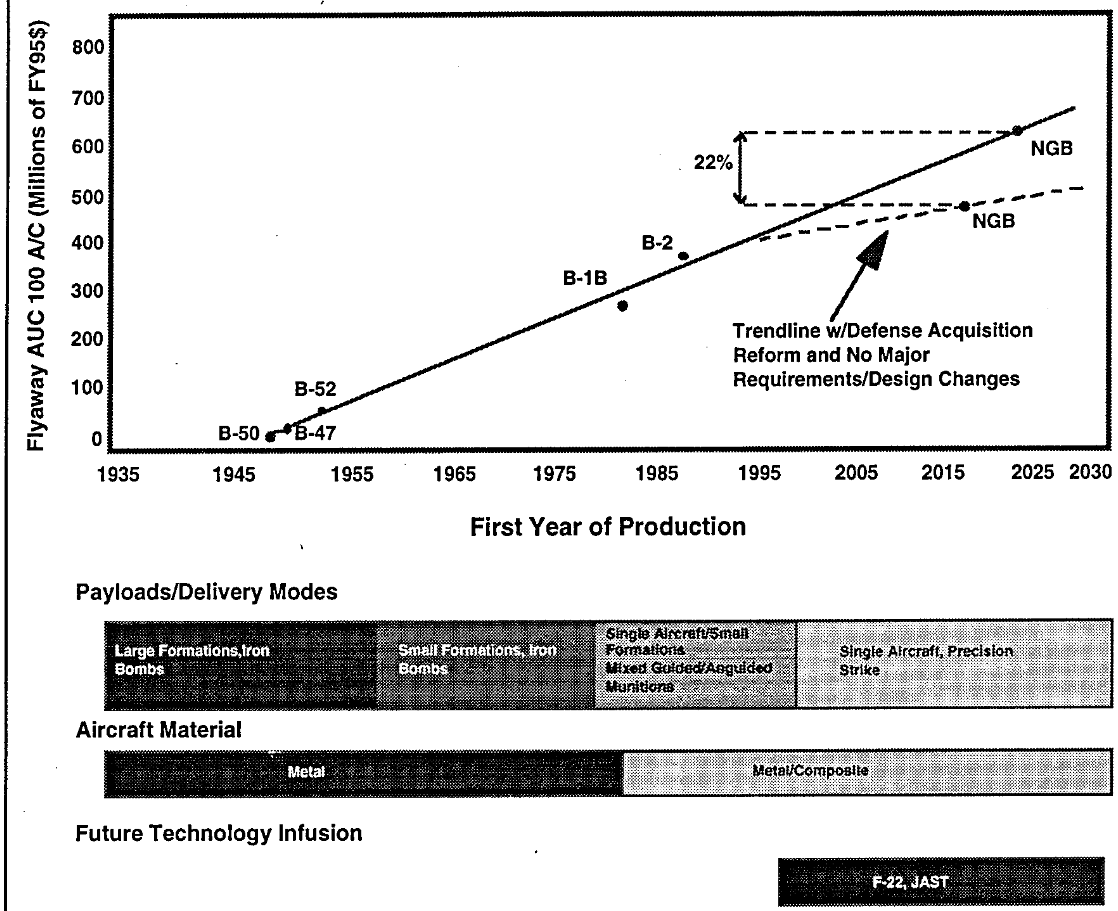
Cost Estimating Methodology — Our cost estimating methodology was based on publicly available data. Because of the uncertainty surrounding an aircraft that won't begin development until 2005, we elected to perform a range estimate. As with our B-2 cost estimate, Alternative 1 is our low cost estimate and Alternative 2 is our high cost estimate. Alternative 1 assumes the initiatives described above are successful and the historic development and production cost growth trends are reduced 50%. Alternative 2 assumes the cost growth trends continue at the historic rate.

Production Cost — Since the NGB technical description was specified in fairly general terms and since the time allocated to perform this cost analysis was very short, we decided to use historical heavy bomber cost data and analogies to the B-1B and the B-2 as our estimating method. We examined the historical cost growth in heavy bomber aircraft from the late 1940s through today. (We also examined fighter and airlifter historical cost growth data -- they both show trends similar to those we found for heavy bombers). Our primary data source was the Seventeenth Edition of *the "U.S. Military Aircraft Data Book, 1995,"*, cited previously. The information presented is as current and factual as any available to the public. It was compiled by fiscal year, primarily from Congressional hearings, DoD authorizations and appropriations, and compared to existing DoD reports. The data has been normalized to FY95 dollars. The first 100 aircraft cost shows the following trends (See Exhibit 8).

Regarding the comparison of the various bomber aircraft: 1) The bomber aircraft shown were built over several decades and were produced at very different quantity buys. (Please refer to the "Background" section of this cost estimate for those quantities.) "Normalizing" the quantity at 100 aircraft is a standard cost analysis technique. 2) The dollars are normalized to the same base year so that the dollars can be directly compared. For example, a 1955 dollar is not "worth" the same as a 1995 dollar. Therefore, we selected a normalized year of 1995 for the comparison. We have included in Exhibit 8 information on the employment of the various bombers, the type of material they used, and the changing penetration/survivability modes for the aircraft.

Once we plotted the normalized cost of the bombers at the 100th unit in FY95 dollars, we calculated a trend line to be used in developing the flyaway cost for the NGB. Once the trend line was calculated, we used that to determine the cost of the NGB. Recall, we wanted to calculate a range estimate vice a single estimate. For Alternative 2 (our high cost estimate), we used the calculated trend line. We started with the first year of production for the NGB for Alternative 2, i.e., FY22, which appears on the "X" axis of Exhibit 8 and went up to the "Y" axis intercept on the trend line to obtain the average unit flyaway cost for the NGB, i.e., $616 million. For Alternative 1 (our low cost estimate) a similar procedure was followed, but first we had to reduce the historical cost growth trend by 50%. Once that was accomplished, we went to the first year of production for the NGB under this alternative, i.e., FY16, and went up to the revised trend line and captured the cost, i.e., $481 million. We now had the flyaway cost for the NGB for both Alternative 1 and 2. But this was for the average unit flyaway cost for 100 production aircraft and our estimate was for only 14 production aircraft. In addition, we needed to break-out the flyaway cost into its recurring and non-recurring components. The following will discuss how we calculated those costs.

Exhibit 8. Heavy Bomber Production Cost Trends



Penetration/Survivability Modes

B-47, B-52	High altitude, ECM, Defensive Guns
B-52	Low Altitude, ECM, Defensive Guns
B-52	Stand-off
B-1	Low Altitude, Speed, ECM, Limited Low Observable
B-1	Stand-off
B-2	High Altitude, Low Observables
B-2	Low Altitude, Low Observables

Recurring Flyaway Cost — Our starting point for both Alternative 1 and 2 was the total flyaway cost, i.e., includes recurring and non-recurring cost, discussed above. Our next step was to separate the recurring and non-recurring costs. We subtracted eight percent of the total flyaway cost to derive an estimate for the non-recurring piece of flyaway cost. The derivation of that percentage is documented below in the non-recurring cost section. The remaining 92 percent, is the recurring flyaway cost. Now that we had isolated the recurring cost from the total cost, we next calculated the first unit cost for both Alternative 1 and 2. This was done by starting with the average recurring unit cost for 100 aircraft and by using cumulative learning curve theory and historical learning curves for heavy bombers we calculated the theoretical first unit cost. The algorithm for the cumulative average cost/quantity curve is as follows:

$\grave{Y}_x = T_1 * X^b$, where:

$\grave{Y}_x$ = The average cost of the first X units,

T_1 = The theoretical cost of the first production unit,

X = The sequential number of the last unit in the quantity for which the average cost is to be computed,

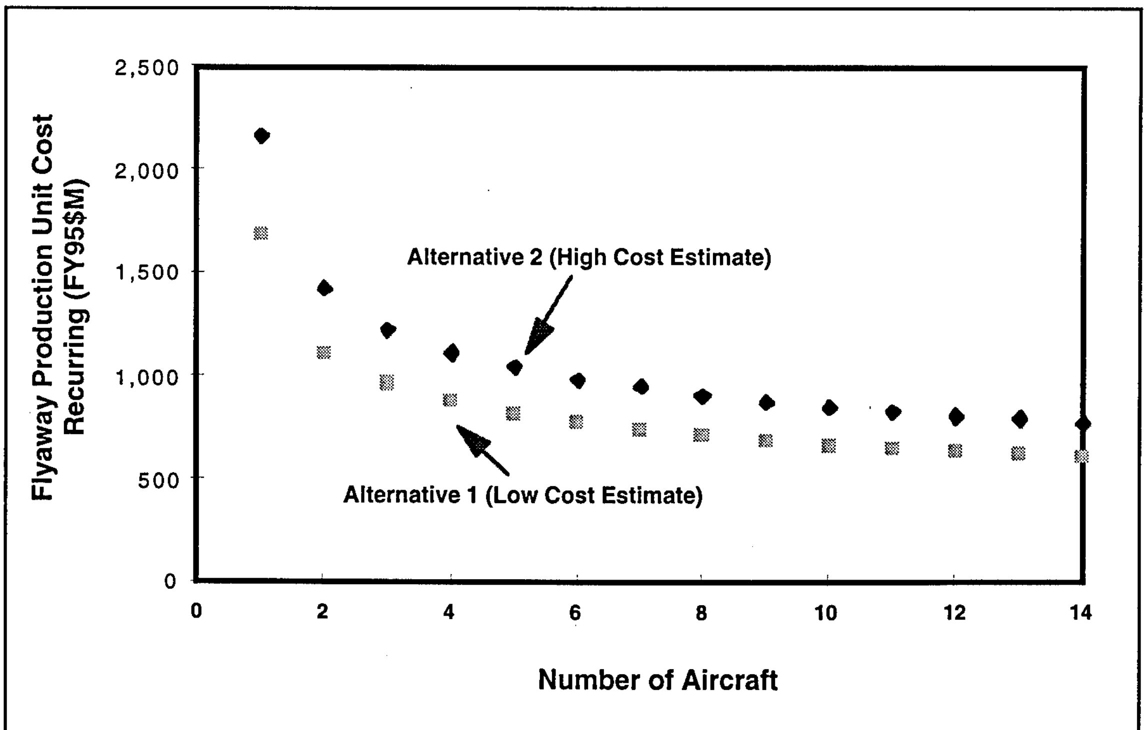
b = A constant reflecting the rate costs decrease from unit to unit.

Exhibit 9 presents the production recurring flyaway cost for each of the 14 NGB aircraft--for both Alternative 1 and 2. Exhibit 10 presents that information in graphic form.

Exhibit 9. NGB Recurring Production Flyaway Cost (FY95 $ M)

Air Vehicle	Alternative 1	Alternative 2
1	1,695	2,172
2	1,110	1,422
3	961	1,231
4	875	1,121
5	817	1,046
6	773	990
7	739	946
8	710	910
9	686	879
10	666	853
11	648	830
12	632	809
13	617	791
14	605	774

Exhibit 10. NGB Learning Curves



Non-recurring start-up — We used an 8 percent factor of total flyaway for both Option 1 (low estimate) and Option 2 (high estimate). This factor was published in November 1992 by the Naval Center for Cost Analysis in the "Standard Cost Factors Handbook". It was based upon a study of 38 fixed and rotary winged aircraft.

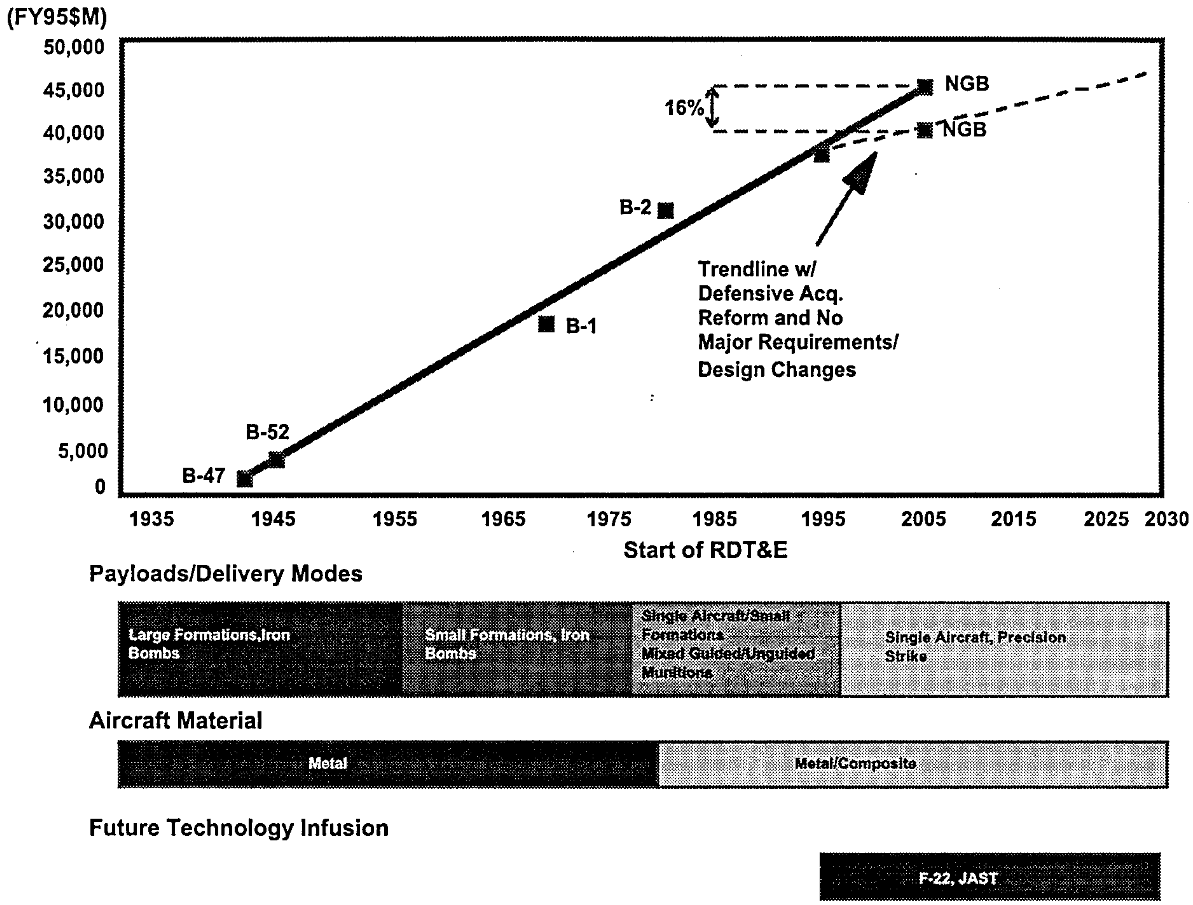
Development Cost — In development, schedule trends for heavy bombers are on the increase. The first B-2 took 8 years from the start of development to first flight and the first operational B-2 took 13 years. It is notable that the time to produce the first fully capable Block 30 aircraft is almost a decade longer. In addition, the development costs have escalated over the decades. Exhibit 11 shows those trends. For Exhibit 11, we normalized the dollars to FY95 dollars in billions so the various aircraft programs could be directly compared. For Alternative 2 (our high cost estimate), we assume that the historical cost trends will continue. For the development cost for Alternative 2, we went into Exhibit 11 in FY05--the start of development for the NGB--and went up to the "Y" axis intercept with the trend line to obtain the development estimate for Alternative 2, i.e., $45,169 million (FY95$). For Alternative 1 (our low cost estimate), we first calculated a 50% reduction to the historical cost growth trend line starting in FY95. We estimate this will save 16% in RDT&E cost. For Alternative 1, we went into Exhibit 11 at FY05--the start of development for the NGB--and went up to the "Y" axis intercept with the revised trend line to obtain our cost estimate for Alternative 1, i.e., $37,843 million (FY95$).

Government Management — Our estimate was based on an analog to the B-1B program. The source of the analog data was the July 1990 "B-1B Annual Cost Estimate" for the production phase. By 1990 the program was essentially complete, so we felt comfortable selecting this analog. This category of cost includes government test, SETA support, mission support, and other. The B-1B SPO estimate was expressed in then year dollars. We converted those dollars to FY95 dollars by using the OSD (Comptroller) inflation rates. NOTE: Since this is an "open the door" cost for running large aircraft programs, the cost is not directly correlated with aircraft complexity. Therefore, an analogy to the B-1 is relevant.

Allowance for Changes — Our estimate was based on an analog to the B-1B program. The source of the data was Rockwell International. The data was provided to us in 1995 dollars. We developed a factor from the Rockwell data. The factor was five percent of the recurring flyaway cost. We cross checked the Rockwell cost with the B-1B SPO FY90 annual estimate and found the estimates to agree.

Support — Support includes support equipment, data and training. This estimate was based upon an analog to the B-1B program. The source of the data was Rockwell International. The data was provided to us in FY95 dollars. The nature of these items tends to be relatable to the number of aircraft being procured. Since there were 100 B-1Bs and only 14 production B-2s, we took 14 percent of the B-1B cost for support and applied it in our estimate of the NGB. The six EMD aircraft will have their support funded with development funds. NOTE: While the NGB has more capability than the B-1 or B-2, it will also be more supportable than either aircraft. Therefore, we believe our estimate is conservative. (Please refer to the O&S section below.)

Exhibit 11. Heavy Bomber Development Cost



Penetration/Survivability Modes

B-47, B-52	High Altitude, ECM, Defensive Guns
B-52	Low Altitude, ECM, Defensive Guns
B-52	Stand-off
B-1	Low Altitude, Speed ECM, Limited Low Observable
B-1	Stand-off
B-2	High Altitude, Low Observables
B-2	Low Altitude, Low Observables

Initial Spares — This cost estimate was based upon an analogy to the B-1B program. The source of the data was Rockwell International. The data was provided to us in FY95 dollars. We developed a factor based upon the Rockwell data. The factor was 7.5 percent of recurring flyaway cost.

Facilities — This estimate was based upon an analogy to the B-2 program. It assumes that the contractor team invests as many resources in the NGB as were invested in the B-2. The aircraft will be built in government owned facilities.

Operations and Support (O&S) — This estimate was based upon the B-2 program. The source of the information was SAF/AQQS (B), from the P-5 Document that supported the B-2 program submitted to Congress with the FY96 President's Budget. The O&S includes: Personnel (Officers, Enlisted, and Civilians), Fuel, Consumables, Repairables, Sustaining Engineering Support, and Interim Contractor support. We used the FY01 value from the P-5, converted it from then year dollars to FY95 dollars using the OSD (Comptroller) inflation rates, and multiplied that times 25 years. We did not change the numbers of personnel from the P-5, but we did decrement the non-personnel costs by 25 percent due to the expected improvements in the NGB over the B-2. The annual O&S cost in FY95 dollars is presented in Exhibit 12. Examples of these improvements include, more efficient engines, significant improvements in electronics and avionics reliability, a more producible and supportable airframe, and less demand for sustaining engineering.

Exhibit 12. Operations & Support Costs (FY95$M)

	B-2 Cost	Adjustment	NGB Cost
Personnel:			
Officers (0-3)	$17.3 Million/year	-0-	$17.3 Million/year
Enlisted (E-5)	$59.7 Million/year	-0-	$59.7 Million/year
Civilian (GS-9)	$55.6 Million/year	-0-	$55.6 Million/year
Fuel	$ 0.2 Million/year	($ 0.05 Million)	$0.2 Million/year
Consumables	$36.2 Million/year	($9.05 Million)	$27.2 Million/year
Repairables	$42.1 Million/year	($10.53 Million)	$31.6 Million/year
Sustaining Engineering Support	$170.4 Million/year	($42.6 Million)	$127.8 Million/year
Contractor Support	$14.2 Million/year	($3.55 Million)	$10.7 Million/year
Total O&S/Year			$330.1 Million/year

Cost Risk Analysis — In cost risk analysis, a probability distribution is selected to measure the uncertainty associated with a particular point estimate. A number of functional forms are available to the risk analyst; the cost risk methodology can incorporate more than 30 different distributions. Because we had only a high and a low cost estimate and it is possible that any answer in between the high and the low estimate could be correct, we selected a uniform distribution. (Note: For this cost estimate no schedule/technical risk analysis was performed.) This cost risk analysis employed a monte carlo simulation to generate a LCC estimate from the high and low cost. Monte carlo simulation refers to the technique for using random numbers to sample from a probability distribution.

The monte carlo simulation technique is widely used to solve problems which are analytically intractable. For this reason, the monte carlo simulation technique is used to randomly sample from the range of cost for each acquisition phase. Repetition of the random process allows the analyst to develop a probability distribution. The result, when performed over numerous iterations, is an estimate of the probabilistic distribution of the LCC. The mean/expected value of the resulting distribution is presented as the most likely cost estimate (including risk) for the LCC. Because we had a uniform distribution, the monte carlo simulation yields an average of the high and low estimate, i.e., $68.14B (FY95$), at the 50th percentile, i.e., there is an equal probability of under running or over running (please refer to Exhibit 13). The cumulative distribution function allows decision makers to examine cost estimates at points other than the expected value.

Exhibit 13. Percentiles and Cost Estimates for 20 Next Generation Bombers

Percentile	Life Cycle Cost (FY95$B)
0%	62.35
10%	64.91
20%	65.90
30%	66.68
40%	67.43
50%	68.14
60%	68.91
70%	69.67
80%	70.44
90%	71.43
100%	73.93

Our cost estimates for the NGB were presented in the text and are repeated below in Exhibit 14. (NOTE: There are six RDT&E aircraft and 14 production aircraft.)

Exhibit 14. NGB Cost Estimates (FY95$B)

Cost Element	Alternative 1 (Low Estimate)		Alternative 2 (High Estimate)	
Aircraft Production (Recurring)	10.6		13.6	
Government Management	0.8		0.8	
Allowance for Changes	0.5		0.7	
Recurring Flyaway Cost		11.9		15.1
Non-recurring Start-up	0.9		1.2	
Aircraft Flyaway Cost		12.8		16.3
Support Equip, Data, Training	0.4		0.4	
Weapon System Cost		13.2		16.7
Initial Spares	0.8		1.0	
Procurement Cost		14.0		17.7
Facilities	1.0		2.0	
Government Management Cost	0.6		0.6	
RDT&E	37.8		45.2	
Program Acquisition Cost		53.4		65.5
Operations & Support (25 years)	8.3		8.3	
Life Cycle Cost (Before Risk)		61.7		73.8
Life Cycle Cost (After including Risk)		68.1		

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Title	Ref. #	Format	Organization
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5 B-2 Production Base Preservation	79	Briefing	SAF/AQQS(B)
5 Bomber Industrial Base Preservation ? 5302	48	Briefing	B-2 SPO
5 Critical Suppliers	55	Briefing	Northrop Grumman
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ndustrial Base Preservation Backup a Package	49	Briefing	Northrop Grumman
huttle Chronology 1964--1973 tract Concepts to Letter Contracts l III) The Reusability Issue	170	Briefing	National Aeronautics and Space Administration (NASA) Management Analysis Offfice
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Force Assessment of DOD's Report on 1 and Capabilities for Evaluating Heavy nbers	105	Report	United States General Accounting Office (GAO)
Force Bombers Conventional abilities of the B-1B Bomber	108	Testimony	United States General Accounting Office (GAO)
oa 1994 Annual Report	205	Report	Alcoa
ed Signal 1994 Annual Report	201	Report	Allied Signal

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Analysis of Air Force Aircraft Multiyear Procurements with Implications for B-2	38	Report	RAND
Annotated Listing of Materials/ Hardware Required to Support Preservation of Bomber Industrial Base in 1995	52	Briefing	Northrop Grumman
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Answers to Study Questions for TASC Bomber Industrial Base Study	175	Briefing	Northrop Grumman
ASC Cost/Schedule Data Cente4r Brochure	97	Document	Aeronautical Systems Center
Assessment B-2 Depot Support	2	Report	Coopers & Lybrand
B-1B Manufacturing Production Hours	116	Slide	Rockwell International
B-2 Avionics	91	Briefing	Northrop B-2 Division
B-2 Bomber	73	Briefing	Northrop Grumman
B-2 Bomber Cost to Complete 20 Aircraft is Uncertain (Report to Congressional Committees)	103	Report	United States General Accounting Office (GAO)
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Production Review	86	Report	
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Program Curtailment	56	Briefing	Boeing
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DO Memorandum for Distribution ject: Revised Inflation Guidance	182	Memo	BMDO
ing Annual Report	213	Report	Boeing
ɛing's Response to "Why does it take so :h longer to develop a bomber than it :s to develop a commercial airplane?"	188	Briefing	Boeing Northrop Grumman
nber and Airlift Industrial Base ɜssment	10	Report	Wright Laboratory
nber Production Base (BPB) Program c Summary	81	Report	Northrop Grumman
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Contract F33657-87-C-2000 CCP 5302: Proposal Clarification	80	Document	Northrop Grumman
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Cost Data Summary Report B-1B Avionics FSD	100	Document	Boeing Military Airplanes
Cost Estimating System Volume 2 Aircraft Cost Handbook Book 1: selected pages	198	Handbook	Delta Research Corporation
Cost Estimating System Volume 2 Aircraft Cost Handbook Book 2: selected pages	199	Handbook	Delta Research Corporation
Curtailment Program	197	Memorandum	SAF/AQQS(B)
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Economic Report of the President	183	Publication	
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F-22 Engineering/Manufacturing Development Program - Cost Performance Report - September 1994 Final	96	Document	Lockheed Aeronautical Systems C
F-22 Lean Enterprise	12	Report	Boeing, Lockheed, Pratt & Whitne
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X USAF Inflation Rates	184	Data	
m 10-K for Lockheed Martin ·poration	225	Data	Lockheed Martin Corporation
l Scale Development (FSD) Work akdown Structure Detailed Index	126	Reference	B-2 SPO
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ıeral Motors Corporation Form 10-K nual Report for the Year Ended :ember 31. 1994	200	Report	General Motors
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xcel Corporation 1994 Annual Report	203	Report	Hexcel Corporation
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.ustrial Base Assessment Maintenance ɔabilities for Large Airacraft (Phase III)	166	Briefing	
ustrial Base Assessment of B-2 Program rtailment	4	Report	Mid-Atlantic Industrial Analysis Support Office
ustry Study #2 Aircraft	3	Report	National Defense University

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norandum Subject: Transmittal of ırmation to TASC Learning Curve a & Supplier Information	189	Memorandum	Northrop Grumman
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e B-2s Cost Estimate for 3 Aircraft Year	129	Briefing	B-2 SPO
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